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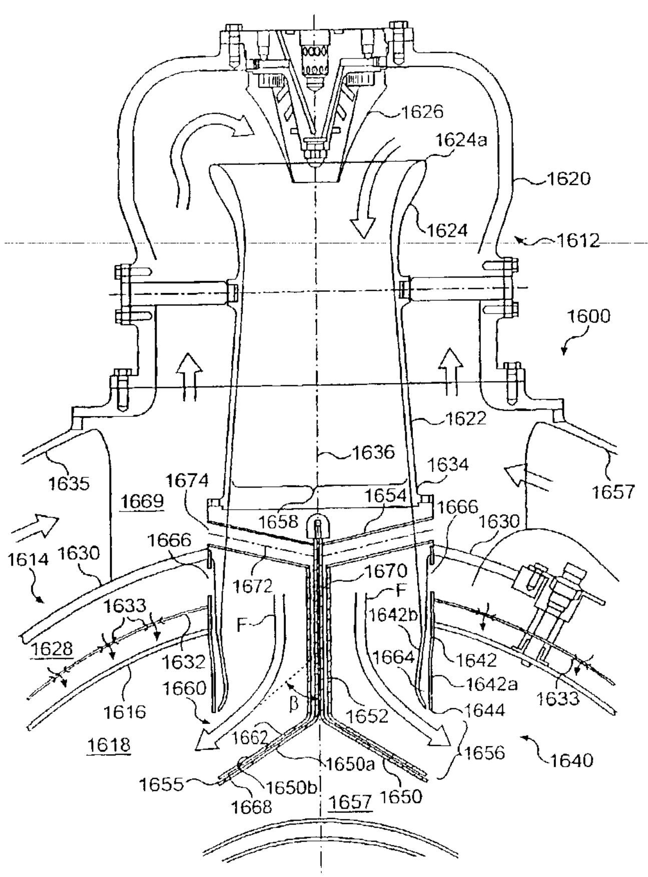

(57) Abstract: A premixer for a single stage combustor system has a venturi-type mixing tube (16, 22) with a flow axis, an inlet (16, 24) adjacent one axial mixing tube end, and a nozzle (16, 40) at the opposite axial mixing tube end. The mixing tube inlet (16, 24) is flow connected to a source of compressed air and a source of fuel, and the mixing tube (16, 22) is connected to a combustion chamber, which can have an annular or can-type liner, at a chamber inlet, and the nozzle extends into the combustion chamber and has at least one port for distributing the fuel/air mixture within the combustion zone. The nozzle includes skirt and plate (16, 50) portions which have respective cooling channels supplied with compressed air to mitigate the effects of flashbacks and burning within the nozzle, air valve and remote from the premixer, while the nozzle cooling channels are fed from the sector of the plenum adjacent the premixer.

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COOLED PREMIXER EXIT NOZZLE FOR GAS TURBINE COMBUSTOR AND METHOD OF OPERATION THEREFOR

This application is related to the inventions disclosed and claimed in application Serial No. 09/033,615, filed March 3, 1998, which is a continuation-in-part of application Serial No. 09/001,628, filed December 31, 1997 (now abandoned), which is a continuation-in-part of application Serial No. 08/779,350, filed January 6, 1997 (now U.S. Patent No. 5,765,363), which is a divisional of Serial No. 08/264,844, filed on July 5, 1994 (now U.S. Patent No. 5,638,674), which is continuation-in-part of Serial No. 08/261,256, filed June 14, 1994 (now U.S. Patent No. 5,481,866), which is a continuation of Serial No. 08/086,833, filed July 7, 1993 (now abandoned). This application also is related to provisional application Serial No. 60/168,681, filed December 12, 1999.

BACKGROUND OF THE INVENTION

Field of the invention:

This invention relates to a combustion system for and method of operation of, gas turbine gas generators, gas turbine engines, or other heat devices, which can produce significant advantages including low levels of pollutants, namely oxides of nitrogen, carbon monoxide, and unburned hydrocarbons. In one aspect, the present invention relates to a system, process, and apparatus for combusting fuel in a gas turbine or gas generator module which significantly lowers pollutants by providing a controllable fuel/air ratio in the combustion zone at all engine operating conditions in addition to thoroughly premixing the fuel and air prior to combustion and, when necessary, completely vaporizing a liquid fuel. In another aspect, the present invention relates to single stage, premixer assemblies for controllable fuel/air ratio gas turbine combustors. In another aspect, the present invention

relates to a mixing tube in a premixer for a combustor system having a flow axis, an inlet port adjacent one axial mixing tube end, and a nozzle at the opposite axial mixing tube end, the mixing tube inlet being flow connected to a controlled source of compressed air and a controlled source of fuel, the mixing tube being connected to the liner housing at a housing inlet port, and the nozzle extending generally along the mixing tube flow axis into a combustion chamber and having at least one port for distributing the fuel/air mixture to a combustion zone or volume. In the present invention, the nozzle is cooled with compressed air to tolerate limited combustion within the nozzle at certain engine operating conditions, notably low power, low speed, and idle conditions to mitigate the effects of unavoidable flashbacks and flame holding by deposits formed in the nozzle.

Description of the Art:

Although gas turbine devices such as engines and gas generators do not produce the majority of the nitrogen oxide emissions released into the earth's atmosphere, reducing those emissions will reduce the total and, in that regard, many countries have enacted laws limiting the amounts that may be released. The reaction of nitrogen and oxygen in the air to form nitrogen oxides, like almost all chemical reactions, proceeds faster at higher temperatures. One way to limit the amount of NO_x formed is to limit the temperature of the reaction. The NO_x produced in gas turbine devices is produced in the combustion process where the highest temperature in the cycle normally exists. Therefore, one way to limit the amount of NO_x produced is to limit the combustion temperature.

Various attempts have been made to limit the combustion temperature and thereby NO_x production in both "single stage" combustors (i.e., those having only a single combustion zone where fuel and air are introduced) and "multistage" combustors, including pilot burners where several, serially connected combustion zones having separate fuel and air introduction means are used. U.S. Patent No. 4,994,149, U.S. Patent No. 4,297,842, and U.S. Patent No. 4,255,927 disclose single stage gas turbine combustors where the flow of compressed air to the combustion zone and the dilution zone of an annular combustor are controlled to decrease the concentration of NO_x in the turbine exhaust gases. In the above combustors, essentially unmixed fuel and air are separately admitted to the combustor, with mixing and combustion concurrently occurring within the same chamber. See also Japanese Laid-Open No. 55-45739. U.S. Patent No. 5,069,029, U.S. Patent No. 4,898,001, U.S. Patent No. 4,829,764, and U.S. Patent No. 4,766,721 disclose two stage combustors. See also German Gebrauchsmuster, 99215856.0. Again, however, fuel and air are provided to each stage at least partially unmixed with complete mixing occurring within the respective combustion zones.

Attempts also have been made to utilize separate premixer chambers to provide a premixed fuel-air flow to a combustor. Japan Laid-Open Application No. 57-41524 discloses a combustor system which appears to premix only a portion of the total fuel flow to a multistage can-type combustor in a separate mixing chamber prior to introduction to the staged combustion chambers. In U.S. Patent No. 5,016,443, a large number of separate fuel nozzles are used to inject fuel into an annular premixer chamber. However, the complexity of the above constructions employing multiple fuel nozzles and fuel splitting

devices can lead to control difficulties, high initial cost, and quenching of the combustion process.

Single stage combustor systems using external premixers are known based on the previous work of the present inventor, such as are disclosed, e.g., in U.S. 5,377,483; U.S. 5,477,671; U.S. 5,481,866; U.S. 5,572,862; U.S. 5,613,357; and U.S. 5,638,674. These systems provide close control of the fuel/air ratio by premixing all of the fuel for combustion with essentially all the combustion air using a venturi-type mixing tube, and introducing the mixture to the combustion zone of the combustor. Significant reductions in gaseous and particulate emissions have been achieved by gas turbine engines and modules over a broad range of operating conditions, employing the inventions disclosed in the above-listed patents.

Also, again based on previous work of the present inventor, such as is disclosed in EP 0 863 369 A3, published September 9, 1998, a premixer of the type contemplated above can include a nozzle assembly protruding into the combustion volume. The nozzle, in addition to distributing the fuel/air mixture in the volume, would accelerate the mixture in order to reduce "flashbacks" from the combustor into the premixer, which can occur when the flame speed is greater than the velocity of the fuel/air mixture in the premixer. Flashbacks can adversely affect the mechanical integrity and performance of the premixer system and related structure. The disclosed premixer system thus sought to reduce flow separation in the premixer caused by the geometrical configuration of the premixer components and also reduce pulsations in the delivery of fuel/air mixture from the premixer into the combustion chamber. These can occur from lack of flame stability in the

combustor due to excessive velocities of, as well as variations in, the mixture velocity exiting the premixer. Pulsations can adversely affect the combustor liner and engine structure.

While the predecessor premixer system acted to deliver fuel/air mixture into the combustion chamber in a controlled direction that would reduce the impingement of flow onto the combustor liner, while maintaining a comparatively simple geometric configuration of the overall design, some impingement nevertheless could occur. Impingement of the flow onto the liner wall can lead to carbon build up and decrease heat transfer performance and increase thermal fatigue. Also, unavoidable flashbacks can occur in the disclosed predecessor system possibly leading to carbon deposits in the premixer nozzle, subsequent flame holding, and possible catastrophic failure of the nozzle resulting in possible damage to the downstream turbine component.

It is therefore desired to provide a premixer system that avoids the problems caused by unavoidable flashbacks and burning within components of the premixer system.

SUMMARY OF THE INVENTION

In accordance with the present invention as embodied and broadly described herein, the combustor system for operation with a source of compressed air and a source of fuel comprises a combustion chamber defining a combustion volume and flow path, and a premixer including a mixing tube operatively connected to the respective sources of fuel and compressed air for providing a premixed fuel/air mixture, the mixing tube including an axis and an exit. The premixer further includes a nozzle cooperating with the mixing tube

exit, the nozzle extending into the combustion chamber for distributing the fuel/air mixture within the combustion volume. The nozzle includes one or more cooling channels operatively connected to the compressed air source for receiving compressed air for cooling.

Preferably the combustion chamber is a single stage combustion chamber and the combustion volume is substantially sealed off from the compressed air source except for compressed air that is admitted from the mixing tube and nozzle cooling channels.

In one preferred embodiment, the nozzle includes a generally cylindrical skirt portion extending from the mixing tube exit peripheral to the mixing tube axis, and a generally conical plate portion positioned on the mixing tube axis with a vertex directed upstream relative to the fuel/air mixture flow direction. The skirt portion and plate portion cooperate to define a nozzle exit having an annular exit flow area. The annular nozzle exit flow area can be less than a mixing tube exit flow area, whereby the fuel/air mixture is accelerated through the nozzle exit.

It is also preferred that the nozzle plate portion is supported by at least one strut with a compressed air passageway interconnected to the compressed air source. The conical plate portion can be a double-walled construction, the walls being spaced apart to define a cooling channel interconnected to the strut passageway. Alternatively, a conical ceramic plate member can be used with cooling channels formed in the strut and an interconnecting bolt.

It is still further preferred that the skirt portion includes a skirt cooling channel. Also, the skirt can be of double-walled construction, the walls being spaced apart to define a cooling channel. Alternatively, a single piece skirt with effusion cooling holes can be used.

Still further in accordance with the present invention as embodied and broadly described herein, the method for controlling the compressed air flow in a radial gas turbine engine to provide cooling and combustion air, the engine having an annular combustion chamber with an external wall convectively cooled by compressed air, such as by impingement cooling, a single premixer assembly operatively connected to the combustion chamber for providing a premixed fuel/air mixture for combustion, the premixer assembly including a nozzle extending into the combustion chamber, the nozzle being cooled by compressed air flowing in one or more channels formed therein, comprises the steps of configuring a nozzle exit area and orientation to deliver a fuel/air mixture for combustion in a portion of the combustion chamber adjacent the premixer; providing compressed air flow to a plenum substantially surrounding the combustion chamber for supplying the nozzle cooling air and combustion air; extracting the combustion air substantially from a first region of the plenum opposed to the combustion chamber portion and extracting the nozzle cooling air substantially from a second region of the plenum adjacent the combustion chamber portion.

The purpose of the nozzle cooling is to permit the premixer system to tolerate combustion internal to the premixer, if such occurs during low load, idle, or low speed operation. That is, the premixer exit area is sized to provide maximum premixer exit velocities less than that which would cause impingement on the combustion liner with the realization that this area value also may cause the minimum exit velocity fall below the fuel/air mixture flame seed resulting in burning within the premixer. Thus portions of the

premixer that would have burning on all sides during operation with burning within the premixer would be susceptible to damage without the present invention.

Other objects and advantages of the invention will be set forth in part in the description which follows, and in part will be apparent from the description, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute part of the specification, illustrate preferred embodiments of the invention and, together with the description serve to explain the principles of the invention.

In the drawings:

Fig. 1A is a schematic cross-section of a predecessor gas turbine engine module utilizing a single stage combustor system having a controlled fuel/air ratio;

Fig. 1B is a schematic end view of the apparatus shown in Fig. 1A taken in the direction AA in Fig. 1A;

Fig. 2 is a schematic cross-section of a gas turbine engine module with an alternative version of the combustor system shown in Fig. 1A;

Figs. 3A-3C are detailed cross-sectional views of a test version of the preferred fuel/air premixer component of the apparatus shown in Fig. 1A;

Fig. 4 is a detailed cross-sectional view of an engine version variation of the fuel/air premixer shown in Figs. 3A-3C;

Fig. 5 is a schematic cross-section of another predecessor gas turbine engine module utilizing a single stage combustor system having a controlled fuel/air ratio;

Fig. 6 is a schematic cross-section of an alternative premixer construction without an integrated compressed air flow valve, for use in the gas turbine engine module shown in Fig. 5;

Fig. 7 is a schematic cross-section of yet another gas turbine engine module made in accordance with certain aspects of the present invention;

Fig. 8 is a schematic cross-section of yet another predecessor gas turbine engine module having a single stage combustor system having a controlled fuel/air ratio;

Figs. 8A is a schematic cross-section of the premixer assembly taken along line 8A-8A of Fig. 8;

Fig. 9 is a schematic cross-section of the premixer assembly taken along line 9-9 of Fig. 8;

Fig. 9A is a schematic cross-section of a variation of the premixer assembly shown in Fig. 9 using a cylindrical air valve, and Fig. 9B is a schematic cross-section of a further modification of the premixer assembly in Fig. 9A;

Fig. 10 is a perspective view of a nozzle assembly for use in the modules depicted in Figs. 8 and 9;

Fig. 11 is a perspective cross-sectional view of the nozzle assembly of Fig. 10;

Fig. 12 is a schematic cross-section of an alternative nozzle for a predecessor premixer system;

Fig. 13 is a schematic cross-section of another predecessor gas turbine engine and module having a can-type combustor;

Fig. 13A is an enlargement of the air valve component depicted in Fig. 13;

Fig. 13B is a schematic cross-section of the nozzle of Fig. 13 assembly taken along line 13B-13B;

Fig. 14A is a schematic cross-section of still another predecessor gas turbine engine module;

Fig. 14B is a schematic perspective end view of a part of the engine module of Fig. 14A;

Fig. 14C is a schematic cross-section through the engine module part depicted in Fig. 14B taken along the line 14C-14C;

Fig. 14D is an enlargement of the portion of Fig. 14A showing the premixer assembly;

Fig. 15A is a longitudinal, schematic cross-section of yet another predecessor engine having a single stage combustor apparatus;

Fig. 15B is a partial end view of the embodiment in Fig. 15A;

Fig. 16 is a schematic cross section showing a premixer made in accordance with the present invention including a premixer exit nozzle with cooling channels for compressed air;

Fig. 17 is a schematic cross section showing another embodiment of a premixer made in accordance with the present invention including an exit nozzle with cooling channels and Figs. 17A and 17B are details of Fig. 17;

Figs. 17C and 17D are schematic and cross-sectional views respectively, of a variation of the embodiment of Fig. 17;

Fig. 18 is a schematic cross-section through an engine combustor made in accordance with the present invention having a premixer with an air-cooled nozzle configured as in Fig. 17, and depicting compressed air flow paths; and

Fig. 19 is a schematic representation of another embodiment of a premixer made in accordance with the present invention including channels for compressed air cooling; Fig. 19A is detail of Fig. 19; and Fig. 19B is a further detail of Fig. 19A.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made to the present preferred embodiments of the invention which are illustrated in the accompanying drawings.

Specifically the embodiments of the present invention are shown in Figs. 16-19 which show premixer constructions having compressed air cooling for premixer exit nozzle components. However, a review of related predecessor gas turbine engine and premixer combustor systems will facilitate a better understanding and appreciation for the present invention.

With initial reference to Fig. 1A, there is shown a predecessor combustor system of the present inventor, which system includes aspects of the present invention and

designated generally by the numeral 10. System 10 is depicted as being used in conjunction with radial gas turbine engine module 12. Gas turbine engine module 12 includes a pressure housing 14 within which is mounted shaft 16 rotatable about axis 18. Mounted on one end of a shaft 16 is radial turbine 20 for driving centrifugal compressor 22 mounted at the opposed end of shaft 16. In the configuration depicted in Fig. 1A, gas turbine engine module 12 power is taken out through a mechanical coupling arrangement shown generally at 24 adjacent centrifugal compressor 22. However, the combustor system of the present invention like the configuration in Fig. 1A, can be utilized in a gas generator in association, e.g., with a "free power turbine" (see Fig. 5A), a "free-jet" propulsion unit (not shown), or any other turbine engine system version as one skilled in the art would immediately realize. Also, the present invention is not limited to use in a radial gas turbine engine or gas generator module but, at least in its broadest extent, could be used with axial or mixed axial-radial turbine engine and gas generator modules as well.

With continued reference to Fig. 1A, gas turbine engine module 12 operates generally as follows. Air enters centrifugal compressor 22 in a direction designated by the arrows 26, is centrifugally accelerated to increase its velocity, whereupon it enters diffuser 28 to increase static pressure. The compressed air exiting diffuser 28 is collected in a plenum chamber 30. Thereafter, compressed air from plenum 30 is mixed with fuel from a fuel source 32 by means of premixer 60 of combustor system 10, to be described in more detail hereinafter, to produce hot exhaust gases which flow past inlet guide vanes 34 to radial turbine 20, where power is extracted. The exhaust gases from turbine 20 are ducted to the atmosphere or to a subsequent engine module. In the case of free power turbine

arrangement, the gases exiting turbine 20 would be ducted to the free power turbine for extraction of further power.

The combustor system in Fig. 1A includes a cylindrical housing defining a combustion chamber, the housing having an axis and having at least one inlet port adjacent one axial chamber end. Importantly, the portion of the chamber adjacent the one axial chamber end comprises a single stage combustion zone. An exhaust is positioned at the opposite axial chamber end, with the portion of the combustion chamber adjacent the opposite axial chamber end comprising a dilution zone. The housing further has aperture means in the form of dilution ports in flow communication with the dilution zone.

With continued reference to Fig. 1A, combustor system 10 includes annular combustor liner housing 40 ("housing" or alternatively referred to as a "liner"), which is generally toroidal in shape. A "can-type" cylindrical housing could also be used. Housing 40 is contained within pressure vessel 14 and defines an axis 42 essentially coincident with gas turbine engine module axis 18. Housing 40 is closed at axial end 44 except for inlet port 43, but is open at axial end 46 to form an annular exhaust port (or combustor exit) 48. Exhaust port 48 is in flow communication with radial turbine 20 through channel 50 past inlet guide vanes 34.

With continued reference to Fig. 1A, toroidal chamber 52 defined by housing 40 comprises two generally axial sections with different functions. Section 54 adjacent axial end 44 comprises a single stage combustion zone and section 56 adjacent housing end 46, comprises a dilution zone. A plurality of apertures 58a, 58b are provided in housing 40 opening into dilution zone 56. Dilution ports 58a are a series of apertures formed in the

outer peripheral surface of housing 40, while dilution ports 58b are a series of apertures formed in an inner peripheral surface of housing 40, relative to housing axis 42. The dilution ports 58a, 58b provide for the introduction of compressed air into the dilution zone 56 of combustion chamber 52 from compressed air conduit means which will be described in more detail hereinafter. However, dilution apertures need not be placed in both inner and outer walls of the combustion liner. For example, apertures 58a may be eliminated if apertures 58b are sized to accommodate the entire dilution flow rate.

As further shown in Fig. 1A, at least one fuel/air premixer disposed outside the cylindrical housing is provided for mixing a portion of the compressed air flow with fuel to provide a fuel/air mixture and delivering the mixture to the combustion zone through the inlet port. The fuel/air premixer includes means for receiving the compressed air, means for receiving the fuel and also chamber means for flow-smoothing the received compressed air and for mixing the received compressed air and fuel. With continued reference to Fig. 1A, combustion system 10 further includes a single fuel/ air premixer designated generally by the numeral 60. Premixer 60 includes housing assembly 62 for receiving the compressed air from conduit means which will be described in more detail hereinafter, and a single fuel nozzle 64 for receiving fuel from fuel source 32 via fuel line 66. Fuel nozzle 64 depicted in Fig. 1A is an "air-blast" type fuel nozzle especially advantageous for use with liquid fuel to provide atomization and thus enhance vaporization. However, use of an "air blast" nozzle with gaseous fuel can provide benefits in terms of providing an initial mixing of the fuel with air prior to admission to the venturi element which will be described hereinafter. Therefore, the combustion system of the

present invention is not restricted to the use of liquid fuel or an "air-blast" fuel nozzle, but gaseous fuel and other types of fuel nozzles, such as swirling-type nozzles, can be used as well.

Fuel/air premixer 60 further includes mixing chamber means in the form of venturi 68 having venturi inlet 70 disposed within fuel/air premixer housing assembly 62 and venturi exit 72 connected to inlet port 43. Venturi 68 defines a flow axis 74, and fuel nozzle 64 is positioned to deliver a fuel spray into venturi inlet 70 substantially along axis 74. The cross sectional flow area and dimensions of venturi 68 are chosen to provide vigorous and complete mixing of the fuel and compressed air within the venturi chamber and a directed flow of the resulting mixture along venturi axis 74 to combustion zone 54, such as indicated schematically by arrow 76. The flow area of venturi exit 72 should be chosen such that minimum velocities of the mixture (i.e., during idle) are greater than the flame propagation speed of the fuel/air mixture. Flame holder means such as depicted schematically as 78 may be provided proximate venturi exit 72 to enhance the stability of combustion in combustion zone 54.

As best seen in Fig. 1B, mixing venturi 68 is disposed such that venturi axis 74 is oriented substantially tangentially with respect to housing axis 42 such that the incoming fuel/air mixture is caused to swirl about axis 42 within the combustion zone 54. It has been found using the preferred premixer construction to be described in more detail henceforth that combustion chamber 52 can be adequately fed by using only a single fuel/air premixer fed by a single fuel nozzle. However, the present invention contemplates the possible use of multiple fuel/air premixers, particularly for situations wherein the radial "thickness" of

combustion chamber 52 is small relative to the outer radius thereof, as measured from axis 42.

The predecessor combustor system in Fig. 1B can also include an ignitor disposed on the cylindrical liner housing at a location adjacent the intersection of the flow axis of the venturi. As depicted herein, ignitor 79 is positioned near the intersection of flow axis 74 and housing 40, and extends at most only a short distance into combustion zone 54. Ignitor 79 is thus ideally positioned to intercept the fuel/air mixture emanating from premixer 60 to initiate combustion. Once started, the swirling hot combustion gases in zone 54 will provide auto ignition of the fuel/air mixture and ignitor 79, which may be electrical, will normally be shut off.

In the depicted system, compressed air conduit means are provided interconnecting the compressor exit and the fuel/air premixer for delivering a portion of the compressed air flow to the premixer compressed air receiving means and for delivering essentially the remaining portion of the compressed air flow to the aperture means for providing dilution air to the dilution zone. With continued reference to Fig. 1A, compressed air conduit means designated generally by the numeral 80 includes generally annular passageway 82 disposed between pressure housing 14 and housing 40. Passageway 82 extends between compressed air receiving plenum 30 and a ring-shaped plenum 84 and is formed as part of pressure vessel 14 adjacent the turbine exhaust section. Fuel/air premixer housing assembly 62 is connected to receive compressed air from plenum 84 for eventual communication to the venturi inlet 70 as explained previously. Plenum 84 is shown having

a circular cross section but other shapes, configurations and locations could be used in the predecessor system.

As can be appreciated from the schematic in Fig. 1A, passageway 82 is configured such that the compressed air flowing therein provides cooling for housing 40, particularly housing portion 86 immediately surrounding the combustion zone 54 where the highest combustion temperatures are expected. Portion 86 of housing 40 is constructed for convection cooling only, with no film-cooling necessary. That is, in portion 86 of housing 40, the housing acts to seal off the compressed air flowing in passageway 82 from the fuel/air mixture being combusted in combustion zone 54. This construction provides for control of the fuel/air ratio of the mixture in combustion zone 54 and permits operation as a "single stage combustor" with a desired lean fuel/air ratio. Such an operation can yield low levels of NO_x and unburned fuel and fuel by-product levels. As will be discussed henceforth, the particular construction of the combustor systems of the type depicted permits extraordinarily low levels of NO_x in comparison with other state of the art combustion systems.

Passageway 82 essentially envelopes combustion chamber 52 to provide convection cooling and also to supply compressed air to dilution ports 58a and 58b. Passageway 82 also may include a channel 82a for channeling compressed air flow for cooling the portion of the pressure vessel 14 adjacent turbine 20, as is shown in Fig. 1A. Turbine inlet guide vanes 34 may be film cooled inlet guide vanes and may be fed from passageway 82 or 82a. Also, compressed air conduit means 80 can include a separate

passageway 88 interconnecting the compressed air receiving plenum 30 and air-blast fuel nozzle 64 when such a nozzle is used, particularly with liquid fuel operation.

As would be understood from the foregoing discussion in conjunction with Fig. 1A, compressed air conduit means 80 acts to channel a portion of the compressed air flow to the fuel/air premixer 60 and to channel essentially the remaining portion of the compressed air flow to the dilution ports 58a and 58b. The compressed air flow not channeled to either the fuel/air premixer or the dilution ports, namely the air used to cool the inlet guide vanes 34, is very small and in any event does not disturb the fuel/air ratio in the combustion zone but merely results in a small further dilution of the exhaust gases prior to entry into turbine 20.

Further, valve means are disposed in the compressed air flow path for determining the compressed air flow rate to the premixer. The compressed air valve means is especially important where the speed of the compressor, and thus the volumetric flow rate of compressed air, is essentially independent of the fuel flow rate, such as the application depicted in Fig. 1A. As embodied herein and with continued reference to Fig. 1A, valve 90 is positioned in fuel/air premixer housing assembly 62 for determining the rate of compressed air flow from plenum 84 to venturi inlet 70. Valve 90 is continuously adjustable, and a suitable construction of valve 90 will be discussed in more detail hereinafter in relation to the description of one preferred construction of the fuel/air premixer of the present invention. When the valve opening changes, the pressure drop over the premixer changes, resulting in an increase or decrease of air mass flow to the

dilution zone. Thus, this variation and dividing of the air flow happen outside the combustor proper.

Fig. 2 discloses predecessor combustor system 110 having an alternate configuration for the compressed air conduit means. Components having the same or similar function relative to the embodiment in Figs. 1A, 1B are given the same numeral but with a "100" base. In the compressed air conduit means designated generally as 180 in Fig. 2, a distribution conduit 181 is provided between compressed air collection plenum 130 and annular passageway 182 surrounding housing 140, and fuel/ air premixer housing assembly 162 is directly connected to distribution conduit 181 upstream of passageway 182. Valve 190 is disposed at the connection between fuel/air premixer housing assembly 162 and distribution conduit 181 to positively divide the air flow into a first portion flowing to fuel/air premixer 160 and the remainder to passageway 182 via distribution conduit portion 181a. As compared with the embodiment in Fig. 1A, where substantially all of the compressed air portion flowing to the premixer was first used to cool at least a part of liner housing portion 86 defining combustion chamber 52, none of the compressed air portion flowing to fuel/air premixer 160 is used to cool portions 186 of housing 140 defining combustion zone 152. However, the Fig. 2 embodiment does allow for the direct control of the compressed air fractions flowing to the fuel/air premixer versus the compressed air flow fraction flowing to the dilution ports 158a and 158b. The configuration shown in Fig. 1A nevertheless provides an ease of construction in assembly of the various components, principally the fuel/air premixer wherein the valve can be integrated directly with the fuel/air premixer housing, as will be discussed in more detail henceforth.

Further in accordance with aspects of the present invention, fuel conduit means is provided interconnecting the fuel supply and the premixer fuel receiving means, the fuel conduit means together with the premixer fuel receiving means establishing a flow path for all the fuel to the premixer. Fuel valve means is disposed in the fuel flow path for determining the fuel flow rate therein. As embodied herein, and with reference again to Fig. 1A, fuel line 66 interconnects fuel source 32 with fuel nozzle 64. Fuel valve 92 is disposed in fuel line 66 immediately upstream of fuel nozzle 64, which is depicted as being an "air-blast" type fuel nozzle particularly suitable for use with liquid fuels, as stated previously.

The predecessor combustor systems in Figs. 1 and 2 include controller means operatively connected both to the compressed air valve means and the fuel valve means for essentially controlling the respective flow rates of the compressed air portion and the fuel delivered to the premixer to provide a preselected lean fuel/air ratio mixture through the inlet port to the combustion zone. As depicted schematically in Fig. 1A, controller 94 which can be either mechanical or electric (e.g., a microprocessor) is interconnected with compressed air valve 90 to essentially control the flow rate of the compressed air flowing directly to venturi inlet 70. While a small portion (typically 5% or less), of the total compressed air flowing to fuel/air premixer 60 can travel through conduit 88 when an "air-blast" nozzle is utilized, the control provided by valve 90 of the remaining 95+% of the compressed air flow is expected to achieve adequate overall fuel/air ratio control. Moreover, for situations utilizing gaseous fuel, such as natural gas as provided in the Example to be discussed hereinafter, conduit 88 could be eliminated such that all of the

compressed air flow to the fuel/air premixer will be under the control of the compressed air flow valve.

Also as depicted in Fig. 1A, controller 94 is operatively connected to fuel valve 92 to meter the fuel flow to fuel nozzle 64. As one skilled in the art would appreciate, controller 94 can act to control both the fuel flow and the compressed air flow to fuel/air premixer 60 to achieve a single preselected fuel/air ratio mixture over the entire operating range of the gas turbine engine module so that the mass flow of the combustible mixture would change as a function of the load. Or, alternatively, controller 94 can be configured to provide a sequence of preselected fuel/air ratio mixtures as a function of load. One skilled in the art would be able to select and adapt a suitable controller for a particular application based on the present disclosure and the general knowledge in the art.

In operation, and with reference to Figs. 1A and 1B, compressed air from compressed air receiving means 30 is channeled via passageway/envelope 82 over the outside surface of housing 40 for cooling housing 40, and particularly portions 86 which surround combustion zone 54. A portion of the compressed air flowing in passageway 82 is admitted to plenum 84 and then flows to fuel/air premixer 60 via the interconnection between fuel/air premixer housing assembly 62 and 84 as controlled by compressed air valve 90 via controller 94. In venturi 68, the compressed air portion is mixed with the fuel from fuel nozzle 64, possibly with a small additional portion of compressed air if nozzle 64 is a "air-blast" type nozzle, and is injected along the venturi axis 74 through inlet port 43 and into combustion zone 54 of combustion chamber 52.

As shown in Fig. 1B, swirling flow and combustion can be provided in combustion zone 54 by locating venturi axis 74 tangentially with respect to axis 42 of the housing. The direction of orientation of the venturi axis 74 is chosen to give a specific angular direction (clockwise or counterclockwise) with respect to the direction of rotation of the turbine in order to provide some aerodynamic unloading of the inlet guide vanes. For the configuration depicted in Fig. 1A and 1B where the fuel/air mixture is admitted to achieve a clockwise swirling combustion in combustion zone 54 as viewed in the direction AA, the direction of rotation of turbine 20 also would be in the clockwise direction. After combustion of the fuel/air mixture in zone 54, the hot exhaust gases pass to dilution zone 56 where dilution air from dilution ports 58a, 58b reduce the average temperature of the exhaust before it is ducted via channel 50 past inlet guide vanes 34 to turbine 20 for work-producing expansion.

The control of combustion afforded by combustion system 10, as well as in accordance with the present invention, through the complete mixing of the fuel and air outside the combustion chamber in the fuel/air premixer, including complete vaporization of the fuel if liquid fuel is used, together with the control of the fuel/air ratio of the mixture delivered to the combustion chamber allows for significant reductions in NO_x levels and the levels of unburned fuel and fuel by-products, as mentioned earlier. Furthermore, the utilization of essentially the total amount of compressed air flow to either combust the fuel or to dilute the exhaust gases upstream of the turbine provides considerable reduction of peak combustor temperatures resulting in longer life for combustor liners compared to conventional combustor designs.

As previously mentioned, the fuel/air premixer of the Figs. 1A and 1B constructions includes a compressed air receiving means, a venturi having an inlet operatively connected to the compressed air receiving means with air flow smoothing means, a fuel receiving means including a nozzle with an exit positioned to deliver a spray of fuel into the venturi inlet substantially along the venturi axis, and valve means associated with the compressed air receiving means for determining the compressed air flow rate to the venturi inlet. With reference to Fig. 3A, fuel/air premixer 260 includes air receiving means in the form of housing assembly 262. Components having a like or similar function to those disclosed in the constructions of Figs. 1A and 1B will be designated by the same numeral but with a "200" base. Housing assembly 262, in turn, includes housing 300 and housing support 302 for mounting housing 300 on pressure vessel 214 of gas turbine engine module 212. Housing support 302 is hollow and, in addition to supporting housing 300 and the components contained therein, acts to channel compressed air from plenum 284 to housing 300. In the construction shown in Fig. 3A, cooling shroud member 303 is positioned between combustion chamber liner housing 240 and pressure vessel 214 for establishing the flow path 282, at least in the vicinity of portions 286 of housing 240 that define the boundary of the combustion zone 254. Shroud member 303 also defines with pressure vessel 214, plenum 284 for collecting the compressed air portion for eventual transmission to housing 300 via housing support 302.

With continued reference to Fig. 3A, fuel/air premixer housing 300 is divided into upstream and downstream compartments 304, 306 respectively by divider plate 308. Aperture 310 is provided in divider plate 308, and a butterfly-type valve plate 290 is

mounted for rotation in aperture 310. In the Fig. 3A construction, the orientation of valve plate 290 in aperture 310 is controlled through control arm 312 (see Fig. 3B) to provide a selective degree of obstruction and, hence, pressure drop. In the orientation of valve plate 290 shown in Figs. 3B and 3C, a minimum amount of obstruction occurs with valve plate 290 being oriented perpendicular to the divider plate 308, corresponding to a "zero" setting of the angular calibration plate 314 shown in Fig. 3C. A position of control rod 312 corresponding to either "9" position on indicator 314 would result in the greatest amount of obstruction and pressure drop in the compressed air portion flowing through aperture 310. As one skilled in the art would realize, the degree of obstruction and thus control of the compressed air flow between upstream compartment 304 and downstream compartment 306 could be varied by changing the angular orientation of control rod 312 between the "zero" and "9" positions, thereby controlling the compressed air flow rate to the balance of the fuel/air premixer 260 which will now be described in more detail.

Divider plate 308 includes an additional aperture 316 in which is mounted inlet 270 of venturi 268. Venturi inlet 270 is configured and mounted to divider plate 308 such that a smooth transition exists between the upper planar surface of divider plate 308 and the inner surface of venturi inlet 270. Venturi 268 extends through upstream housing compartment 304, housing support 302, past pressure vessel 214, combustion chamber liner 303, and connects to housing 240 at the location of inlet port 243. As described previously in relation to the construction depicted in Fig. 1A, the venturi axis 274 which corresponds generally to the flow direction of the fuel/air mixture in venturi 268 can be

oriented to provide a substantially tangential admission direction with respect to the axis (not shown) of annular combustion chamber housing 240.

With continued reference to Fig. 3A, fuel nozzle 264 is mounted in downstream compartment 306 with the fuel nozzle exit 318 positioned to deliver a spray of fuel into venturi inlet 270 along venturi axis 274. Fuel nozzle 264 is of the "swirling" spray type which utilizes ports 320 and swirl vanes 322 to channel some of the compressed air swirl the fuel entering through fuel port 324 before releasing the fuel spray through exit 318. Also shown in Fig. 3A is perforated flow-smoothing element 326 positioned in the downstream compartment 306 and surrounding fuel nozzle exit 318 and venturi inlet 270, to avoid uneven velocities and separation in the venturi which otherwise could result in "flame holding" in the venturi. While a small pressure drop is introduced by its incorporation, the perforated element 326 has been found to provide increased stability for the compressed air flow from downstream compartment 306 past the fuel nozzle 264 and into venturi inlet 270, without any separation at the lip of venturi inlet 270.

Fig. 4 shows a contemplated commercial variation of the predecessor fuel/air premixer depicted in Figs. 3A-3C, which variation is designated generally by the numeral 360. Components having the same or similar function to those described in relation to the Figure 1A, 1B embodiment are given the same numerals but with "300" base. Fuel/air premixer 360 includes a venturi 368 which has inlet 370 which extends slightly above the surface of divider plate 408. Also, fuel nozzle exit 418 extends a distance into venturi inlet 370. One skilled in the art would realize that the optimum performance of the fuel nozzle 364 in conjunction with the venturi 368 (as well as nozzle 264 and venturi 268 in the

variation shown in Figs. 3A-3C) may vary from application to application and that the positioning of fuel nozzle exit 418 along the venturi axis 374 in the vicinity of venturi inlet 370 may be adjusted to determine the optimum position. However, it is anticipated that perforated screen element 426 would provide flow stability for the Fig. 4 embodiment as well. Finally, the Fig. 4 construction incorporates contemplated refinements in the construction of the fuel/air premixer compared to the construction shown in Fig. 3A, such as the use of integral, bell-shaped housing 400.

As mentioned previously, certain aspects of the present invention advantageously can be adopted for applications such as gas turbine gas generator modules used in conjunction with free power turbines or free jet propulsion units, which gas generator modules may not require the use of a compressed air flow valve and associated controller functions, in contrast to the previously discussed constructions depicted in Figs. 1A and 2. Fig. 5A depicts schematically such a predecessor engine system, which could be adapted also to use the present invention, designated generally by the numeral 500. Engine 500 comprises gas turbine gas generator module 512, including combustor system 510 to be discussed in more detail hereinafter and free power turbine module 513. Free turbine module 513 includes free turbine 513a which is depicted as an axial turbine, but could be pure radial or mixed axial-radial as the application may require. In comparison with the Fig. 1A engine system where power was extracted from gearing 24 connected to shaft 16, power is taken from the engine system 500 in the Fig. 5A embodiment via gearing associated with free turbine shaft 513b. Although shown coaxial with axis 518 of the gas generator module, rotational axis 513c of free power turbine 513 could be angularly

displaced to meet the requirements of the overall system 500. In the subsequent discussion, like components relative to the construction in Fig. 1A will be given the identical numeral but with a "500" prefix.

Specifically, gas turbine gas generator module 512 includes a mechanically independent spool, namely centrifugal compressor 522 and radial turbine 520 mounted for dependent rotation on shaft 516, inside pressure housing 514. Thus, shaft 516 can rotate independently of free turbine shaft 513b although gas generator 512 and free turbine module 513 are interconnected in the gas flow cycle. Module 512 also includes combustor system 510 with combustor liner housing 540 which is contained within pressure housing 514 and which receives premixed air/fuel from external premixer 560 through inlet port 543 along venturi axis 574. Venturi axis 574 is oriented tangentially with respect to axis 542 of annular combustor liner housing 540 to provide efficient, swirling combustion and also to partially unload inlet guide vanes 534, as discussed previously in relation to the Fig. 1A embodiment. See Fig. 5B.

Fig. 5B also depicts ignitor 579 positioned on liner housing 540 adjacent the intersection of venturi axis 574. While it may eventually be possible to locate the ignitor in a relatively cooler environment, such as in the premixer, and thereby prolong ignitor life and further decrease the number of penetrations in liner housing 540, the location depicted in Fig. 5B may be useful to ensure light-off because of the low velocities of the fuel/air mixture in the annular chamber.

In the constructions depicted in Figs. 5A and 5B, housing liner 540 and pressure housing 514 cooperate to form passages for the compressed air flow from compressor

plenum 530. Also included in this engine construction is annular cooling shroud 583 disposed between, and radially spaced from both, housing liner 540 and the circumferentially adjacent portion of pressure housing 514. As can be appreciated from the figures, cooling shroud 583 and housing liner 540 cooperate to form part of the passageway 582 for convectively cooling the combustor chamber defined by liner 540 while cooling shroud 583 and pressure housing 514 cooperate to form annular plenum 584 to collect the portion of the compressed air flow to be channeled to premixer 560 for mixing with the fuel. In the Fig. 5A construction, as in the construction shown in Fig. 1A, a portion of the compressed air is taken from the passageway leading from the compressor exit after providing convective cooling and is then channeled to the premixer for mixing with fuel, but the Fig. 5A arrangement can be made more structurally compact than the ring-shaped plenum 84 in Fig. 1A. Furthermore, cooling shroud 583 provides radiation shielding of the adjacent parts of pressure housing 514 from the relatively hot liner housing 540, allowing the use of less expensive materials and increasing the service life of the pressure housing.

The balance of the compressed air flow in passageway 582 is channeled through dilution apertures 558b. There are no dilution ports corresponding to the ports 58a in the Fig. 1A embodiment, but dilution ports 558b include two separate circumferential port sets $558b_1$ and $558b_2$. Divider 559 and the sizing of ports $558b_1$ and $558b_2$ causes dilution air flowing through ports $558b_2$ to first flow through passageway 582a past turbine shroud 557. One skilled in the art would be able to perform the required sizing analysis to provide adequate distribution of the dilution air to achieve desired turbine shroud cooling. The elimination of film cooling provides for control over the fuel/air ratio in the combustion zone

554 and is one of the highly significant benefits and advantages of the predecessor constructions, as well as the embodiments of the present invention, as explained henceforth in relation to Figs. 16-19.

Fig. 5A also shows (in dotted line) conduit 588 leading from compressor exit plenum 530 to premixer 560 in the event "air-blast" type liquid fuel nozzle is utilized, for reasons explained previously. Although shown penetrating compressor plenum-exit 530 axially inclined in Fig. 5A for clarity, the inlet to conduit 588 would be tangential and in the axial plane of the compressor exit to capture the total dynamic head. One skilled in the art would be able to design an appropriate inlet configuration given the present description.

Aside from the small amount of compressed air that may be required to operate an air blast-type liquid fuel nozzle and, possibly, for inlet guide vane cooling, all of the compressed air is used to convectively cool at least part of liner housing 540 before being used for mixing with the fuel or for dilution. This construction optimizes the convective cooling capacity of the compressed air inventory. A gas generator variation corresponding to the Fig. 2 predecessor construction also was contemplated where the compressed air flow portion used for mixing with the fuel is not first used for convective cooling. The simplified construction of such a system might outweigh the reduction in cooling capacity and therefore be desired for certain applications.

As depicted in Fig. 5A, air is channeled from passageway 582 through annular plenum 584 for mixing directly with the fuel in premixer 560. Fig. 5A depicts compressed air valve 590 by broken lines to indicate that the valve is optional. It may be used for "fine tuning" the fuel/air ratio during operation, it may be preset to a fixed opening for operation,

or it may be eliminated entirely, for the following reason. In engine system 510, the speed of compressor 522 and thus the compressed air flow rate is essentially proportional to the fuel flow over the operating range. Hence, gross control of the fuel/air ratio to a preselected lean value can be achieved automatically. The function of controller 594 acting to control fuel flow to fuel nozzle 564 from source 532 through fuel valve 592 thus becomes similar to that of a conventional throttle responsive to power demands.

While premixer 560 channels all the fuel/air mixture to combustion zone 554 required over the intended operating range of engine system 510, an auxiliary fuel supply system such as system 596 depicted in Fig. 5B may be used to provide a richer mixture for start-up and idle conditions. System 596 includes a conventional fuel spray nozzle 597 fed from fuel source 532 (see Fig. 5A), and the auxiliary fuel flow rate can be controlled by controller 594 through valve 598. In the disclosed embodiment, spray nozzle 597 is positioned to penetrate liner housing 540 adjacent venturi outlet 572 and disposed radially. However, nozzle 597 can be positioned in an opposed tangential orientation relative to venturi 570 (not shown) to enhance mixing with the fuel/air mixture entering through venturi 570. Other positions, constructions and orientations of spray nozzle 597 are, of course, possible.

Fig. 6 is a schematic of an alternative "valve-less" predecessor premixer design which could be used in engine system 510, and which is designated generally by the numeral 660. Premixer 660 includes housing 662, fuel nozzle 663 which is of the type having peripheral swirl vanes 665, and venturi 668 oriented with venturi axis 674 tangential to the combustor axis (not shown). Also, perforated flow-smoothing member 667

surrounds nozzle 664 and the entrance to venturi 668, for reasons explained previously in relation to the corresponding components in the "valved" construction in Fig. 3A. Premixer 660 additionally includes heating means such as electric resistance heater jacket 669 surrounding the throat area of venturi 668 and operatively connected to a power source (not shown) via electrical leads 671. During start up and using liquid fuels, a film of fuel tends to collect on the venturi inner surface. Heater jacket 669 augments vaporization of this fuel film and thus promotes the overall mixing of the fuel and air in the premixer. During operation, the temperature of the compressed air portion flowing past the outer surface of venturi 668 from plenum 684 may provide sufficient heat for vaporizing a liquid film, or prevent the formation of a liquid fuel film altogether, thereby dispensing with the need for continued activation of heating jacket 669.

Fig. 7 schematically depicts yet another engine construction that may also advantageously utilize the apparatus of the present invention to be described henceforth, namely, a gas turbine engine system such as described in my previous patent U.S. Patent No. 5,081,832, the disclosure of which is hereby incorporated by reference. In the Fig. 7 embodiment, engine system 700 includes high pressure spool 711 and mechanically independent low pressure spool 709. Low pressure spool 709 includes low pressure compressor 701 which is driven through shaft 702 by low pressure turbine 703. The compressed air exiting low pressure compressor 701 flows through diffuses 704 and enters high pressure compressor 722 for further compression. As components of high pressure spool 711 high pressure compressor 722 is driven by high pressure turbine 720 via shaft 716. Gases exhausted from high pressure turbine 720 are diffused in diffuser 705 and

then expanded in low pressure turbine 703. For reasons explained more fully in U.S. Patent No. 5,081,832, net power is taken from engine system 700 via gearing 724 connected to shaft 716 of high pressure spool 711. Low pressure spool 709 is used principally to supply pre-compressed air to high pressure spool 711 and possibly to drive engine support systems (e.g., lubrication).

As seen in Fig. 7, engine system 700 includes combustor system 710 to provide hot combustion gases to high pressure turbine 720 by combusting fuel with a portion of the compressed air from high pressure compressor 722. Importantly, combustor system 710 uses external premixer 760 which includes fuel nozzle 764 (which may be an "air-blast" type receiving compressed air directly from compressor 722 via conduit 788 with a tangential inlet-shown dotted) and venturi 768 to supply fully premixed fuel/air tangentially to annular combustion zone 754 defined by liner housing 740. Cooling shroud 783 and liner housing 740 cooperate to define part of convective cooling passageway 782, while cooling shroud 783 and the circumferentially adjacent portion of pressure housing 714 cooperate to form annular plenum 784 to channel a portion of the compressed air to premixer 760. The balance of the compressed air flow is used for additional convective cooling and finally dilution, using a configuration and construction similar to that shown in Fig. 5A.

However, the engine system configuration shown in Fig. 7 is intended for producing power at essentially constant high pressure spool shaft speed. Like the Fig. 1A construction the total compressed air flow rate will not automatically adjust to a changed fuel flow in the manner of gas generator module 512 in the Fig. 5A construction. As a

result, combustor system 710 specifically includes compressed air valve 790 integrated with premixer 760 and under the control or controller 794, which also controls fuel valve 792, to achieve a preselected lean fuel/air ratio. It is understood that, although not shown, the Fig. 7 construction could include features described in relation to the other predecessor constructions including a liner-mounted ignitor, auxiliary fuel spray system, staged dilution ports, etc.

Fig. 8 schematically depicts yet another engine embodiment that could advantageously utilizes certain aspects of the present invention to be described henceforth. With initial reference to Fig. 8, a combustor system is shown and designated generally by the numeral 810. (Note, the upper portion of combustor system 810 is a cut-away view, illustrating the upper cross-sectional half of the system.) System 810 is depicted as being used in conjunction with radial gas turbine engine module 812. Gas turbine engine module 812 includes a pressure housing 814 within which is mounted shaft assembly 816 rotatable about axis 818. Mounted on one end of shaft assembly 816 is radial turbine 820 for driving centrifugal compressor 822 mounted at the opposed end of shaft assembly 816. In the configuration depicted in Fig. 8, power from gas turbine engine module 812 is taken out through a mechanical coupling arrangement shown generally at 824 adjacent centrifugal compressor 822. However, the combustor system can be utilized in a gas generator in association e.g., with a "free power turbine," a "free-jet" propulsion unit, or any other turbine engine system version as one skilled in the art would immediately realize. Also, the combustion system is not limited to use in a radial gas turbine engine or

gas generator module but, at least in its broadest extent, could advantageously be used with axial or mixed axial-radial gas turbine engines and gas generator modules as well.

With continued reference to Fig. 8, gas turbine engine module 812 operates generally as follows. Air enters centrifugal compressor 822 in a direction designated by the arrows 826, is centrifugally accelerated to increase its velocity, whereupon it enters diffuser 828 to increase static pressure. The compressed air exiting diffuser 828 is collected in a plenum 830. Thereafter, a portion of the compressed air from plenum 830 is mixed with fuel from a fuel source 832 by means of premixer assembly 860 of combustor system 810, to be described in more detail hereinafter, to produce hot exhaust gases which flow past inlet guide vanes 834 to radial turbine 820, where power is extracted. The exhaust gases from turbine 820 are ducted to the atmosphere or to a subsequent engine module. For example, in the case of free power turbine arrangement, the gases exiting turbine 820 would be ducted to the free power turbine for extraction of further power.

The combustor system in Fig. 8 includes a cylindrical combustor liner defining a combustion chamber, the liner having an axis and having one or more inlets adjacent one axial chamber end. The portion of the chamber adjacent the one axial chamber end comprises a single stage combustion zone. With continued reference to Fig. 8, combustor system 810 includes annular combustor liner 840 which is generally toroidal in shape. Housing 840 is contained within pressure vessel 814 and defines an axis 842 essentially coincident with gas turbine engine module axis 818. Liner 840 is closed at axial end 844 except for inlet 843, but is open at axial end 846 to form an annular combustor exit 848. (If multiple premixers are utilized, it should be understood that additional inlets may be

provided in the liner to accommodate the added premixers.) Combustor exit 848 is in flow communication with radial turbine 820 through channel 850 past inlet guide vanes 834.

With continued reference to Fig. 8, toroidal chamber 852 defined by liner 840 comprises two generally axial sections or portions with different functions. Region 854 adjacent axial end 844 comprises a single stage combustion zone (e.g., a combustion volume) and region 856 adjacent liner end 846, comprises a dilution zone. A plurality of ports 858 are formed in the outer peripheral surface of liner 840 and open into dilution zone 856. Dilution ports 858 provide for the introduction of compressed air into the dilution zone 856 of combustion chamber 852 from a compressed air conduit, which will be described in more detail hereinafter. Alternatively, compressed air may be delivered into the dilution zone through a second set of dilution ports (not shown) provided as a series of apertures formed in an inner peripheral surface of liner 840 by redirecting compressed air from the premixer into the dilution zone.

Further, one or more fuel/air premixer assemblies are each disposed relative the cylindrical liner and are provided in the Fig. 8 construction for mixing a portion of the compressed air flow with fuel to provide a fuel/air mixture and for delivering the mixture to the combustion zone through the respective liner inlet. The fuel/air premixer assembly includes an air inlet for receiving the compressed air, a fuel inlet for receiving the fuel and also a mixing tube for flow-smoothing the received compressed air and for mixing the received compressed air and fuel. Essentially all of the air used during combustion is delivered to the combustion zone through one or more fuel/air premixer assemblies. The

combustion zone is otherwise sealed off from receiving compressed air except through the premixer assembly.

With continued reference to Figs. 8 and 8A, combustion system 810 further includes a single fuel/air premixer assembly designated generally by the numeral 860. Premixer assembly 860 includes housing assembly 862 for receiving the compressed air through an air inlet 861 from an air conduit (described later), and a fuel nozzle 864 for receiving fuel through a fuel inlet 865 from fuel source 832 via fuel line 866. Fuel nozzle 864 depicted in Fig. 8 is an "air-blast" type fuel nozzle that mixes the fuel with swirling compressed air that is especially advantageous for use with liquid fuel to provide atomization and thus enhance vaporization. However, use of an "air blast" nozzle with gaseous fuel can provide benefits in terms of providing an initial mixing of the fuel with air prior to admission to the venturi element. Thus, the combustion system of Fig. 8, as well as that of the present invention, can use not only liquid fuel or an "air-blast" fuel nozzle, but also gaseous fuel and other types of fuel nozzles, such as other swirling-type nozzles. As shown in Fig. 8A, an auxiliary fuel nozzle 867 may be provided for use during the start-up sequence of combustor system 810.

The mixing tube, such as the venturi in the Fig. 8 construction, has a flow axis substantially radially disposed with respect to the combustion liner axis, an inlet adjacent one mixing tube axial end, and a nozzle assembly is included at the opposite mixing tube axial end. The mixing tube inlet is flow connected to the premixer air inlet and the premixer fuel inlet. The mixing tube is connected to the liner inlet, and the nozzle assembly extends into the combustion chamber along the flow axis to deliver the fuel/air mixture within the

combustion zone. However, as compared to the premixer nozzles of the present invention, to be discussed henceforth in relation to Figs. 16-19, the nozzle of the predecessor Fig. 8 construction was uncooled and not able to tolerate burning within the nozzle. Rather, the design philosophy surrounding the predecessor systems using exit nozzles, such as Fig. 8, was to avoid all burning in the nozzle including at low power, low speed operation, and idle conditions.

With continued reference to Fig. 8, premixer assembly 860 further includes a mixing chamber in the form of a venturi-type mixing tube 868 having mixing tube inlet 870 disposed within fuel/air premixer housing assembly 862 and connected to liner 840 at inlet 843. Further, mixing tube 868 has a nozzle assembly 872 for delivering fuel/air mixture into the combustion chamber that is connected to a portion of the mixing tube that extends into combustion zone 854. Mixing tube 868 defines a flow axis 874, and fuel nozzle 864 is positioned to deliver a fuel spray into mixing tube inlet 870 substantially along axis 874. The cross-sectional flow area and dimensions of mixing tube 868 are chosen to provide sufficient residence time to obtain vaporization and mixing of the fuel and compressed air within the mixing tube and to direct the flow of the resulting mixture along mixing tube axis 874 to nozzle assembly 872. Preferably, the residence time of particulate matter in the mixing tube is between 2-8 milliseconds. Although the mixing tube depicted in Fig. 8 is a venturi-type mixing tube 868, one skilled in the art would appreciate that other geometrical configurations are possible, including conically or cylindrically shaped mixing tubes, for example.

As further shown in Fig. 8, compressed air conduit includes generally annular cooling passageway 882 disposed between liner 840 and a second, outer annular liner 841. Passageway 882 extends between compressed air plenum 830 and dilution ports 858. Fuel/air premixer housing assembly 862 is connected to receive compressed air from orifices 885 in liner 841 for eventual communication to the mixing tube inlet 870 by delivering the air through plenum 884 and valve 890 (discussed later).

As can be appreciated from the schematic in Fig. 8, passageway 882 is configured such that the compressed air flowing therein provides cooling for liner 840, particularly liner portion 886 immediately surrounding the combustion zone 854. Portion 886 of liner 840 is constructed for convection cooling only, with no film-cooling. That is, in portion 886 of liner 840, the liner acts to seal off the compressed air flowing in passageway 882 from the fuel/air mixture being combusted in combustion zone 854. Passageway 882 envelopes combustion chamber 852 to provide convection cooling and also to supply compressed air to dilution ports 858. This construction provides for control of the fuel/air ratio of the mixture in combustion zone 854 and permits operation as a "single stage combustor" with a desired lean fuel/air ratio. Such an operation can yield low levels of NO_x and unburned fuel and fuel by-product levels and thus is also preferred for use with the premixer nozzle constructions of the present invention.

Further shown in Fig. 8A, a valve 890 is positioned in fuel/air premixer housing assembly 862 for determining the rate of compressed air flow from plenum 884 to mixing tube inlet 870. Valve 890 is continuously adjustable, and a suitable construction of valve 890 can vary, but is depicted as a butterfly-type. When the valve opening changes, the

pressure drop over the premixer changes, resulting in an increase or decrease of air mass flow. A controller 894 (depicted schematically), which for example, can include a microprocessor, is interconnected with valve 890 to essentially control the flow rate of the compressed air flowing directly to mixing tube inlet 870. Controller 894 is also operatively connected to a fuel valve to meter the fuel flow to fuel nozzle 864. As one skilled in the art would appreciate, controller 894 can act to control both the fuel flow and the compressed air flow to premixer assembly 860 to achieve preselected fuel/air ratios—e.g., preselected in accordance with atmospheric conditions, operating conditions, and fuel-type—over the entire operating range of the gas turbine engine module. Controller 894 could provide infinitely variable fuel/air ratios or step-type ratios. One skilled in the art would be able to select and adapt a suitable controller for a particular application based on the present disclosure and the general knowledge in the art.

With reference to Figs. 9-11, nozzle assembly 872 extends along the mixing tube flow axis into the combustion chamber and has one or more ports for distributing the fuel/air mixture within the combustion zone. The nozzle assembly further may have at least one channel for each nozzle assembly port, wherein each channel is angled away from the mixing tube flow axis and terminates at a nozzle assembly port for distributing the fuel/air mixture within the combustion zone.

Specifically, nozzle assembly 872 is positioned within combustion chamber 852, and has channels 901 defined by the geometrical configuration of end cap 903 and interior side walls 905 of nozzle assembly 872. Side walls 905 can be configured as an extension member for mixing tube 868 or can have different geometrical shape. Nozzle assembly

872 further includes ports 907 defined by end cap 903 and side walls 905. Ports 907 are in flow communication with channels 901 and distribute fuel/air mixture within combustion zone 854. Fins 909 are additionally provided to connect end cap 903 to side walls 905.

Due to the beveled or sloped surfaces of the nozzle assembly (and in particular channels 901), the flow of the fuel/air mixture is directed away from flow axis 874, as can be seen by the arrows in Fig. 11. That is, the flow of the fuel/air mixture can be diverted in a desired direction by utilizing surfaces of varying geometrical orientations. Although several channels and nozzle assembly ports are depicted, it is understood that the present invention can be achieved by utilizing only a single channel and associated port. However, at least two ports for delivering the fuel/air mixture in opposed angular directions relative to the liner axis is particularly beneficial in utilizing the overall combustion volume in the annular construction depicted in Figs. 9-9B.

Further, the structural components of the nozzle assembly (and in particular channels 901) can be configured to direct the fuel/air mixture into the combustion zone in a variety directions, with the flow preferably not impinging the walls of the combustion liner. For example, channels 901 of the nozzle assembly 872 could be configured so that the fuel/air mixture flows into the combustion zone in substantially radial or mixed radial-axial directions and angles away from the mixing tube flow axis. Further, the flow could be directed in multiple directions relative to the liner axis, e.g., along at least two generally opposed, substantially tangential angular directions relative to the combustion chamber liner axis as is shown by the arrows in Fig. 9. Of course, flow along the chamber axis is also contemplated. Moreover, the channels 901 could also be configured to direct flow in

more than two directions and angles relative to the mixing tube axis, such as is depicted in Figs. 10 and 11.

It should be further understood that the aforementioned geometry of nozzle assembly 872 advantageously provides a flame holding effect by causing the sudden expansion and recirculation of the exiting fuel/air mixture in the vicinity of end cap 903. That is, the configuration of end cap 903, for example, provides areas 911 for the circulating fuel/air mixture to burn outside nozzle assembly 872 adjacent ports 907. Flame holding is beneficial in providing a stable flame near ports 907 in order to maintain a steady flame front to stabilize combustion during the varying operating conditions.

In the constructions depicted in Figs. 9-11, the total cross-sectional area of ports 907 are collectively about 70-90% of the cross-sectional area of mixing tube 868 (generally indicated at reference point 913) in order to accelerate the fuel/air mixture and thereby increase the mixture velocity delivered into combustion chamber 852 relative to the velocity in the mixing tube 868. The significance of this feature can be appreciated from understanding that flames from chamber 852 could otherwise ignite fuel within mixing tube 868 when the flow of fuel/air mixture is at a low speed relative to the flame speed in combustion zone 854. By utilizing ports 907, sized to increase the velocity of the flow of fuel/air mixture, the likelihood that flame from combustion chamber 852 will "flashback" into the mixing tube is reduced. Further, by increasing the velocity of the flow, it is believed that the boundary layer along channels 901 and at ports 907 is reduced, thereby eliminating low velocity regions where the flame from combustion chamber 852 can creep along the surfaces of nozzle assembly 872 and flashback into mixing tube 868. It is also believed

that the aforementioned geometry is particularly useful when fuel/air mixture velocity variations occur in mixing tube 868, which otherwise could cause variable flame fronts or pulsations within combustion chamber 852. The increased pressure at ports 907 also can dampen the minor variation in mixture velocity in the premixer and reduce such pulsations. These advantages are useful in maintaining the structural integrity of the combustor system and its individual components, and thus provide a benefit to the integrity and performance of the overall gas turbine engine itself.

FIG. 9A depicts a variation of the construction shown in Figs 8 and 9 with the principal differences being that the premixer 860' includes a cylindrical-type air valve 890' in place of the butterfly-type air valve 890 and an asymmetric nozzle assembly 872' arrangement. Air valve 890' has a rotatable inner cylinder section 890a', which progressively increases or diminishes the amount that valve outlet opening 890c' is occluded to permit more or less air flow through valve 890' upon rotation of the cylinder/sleeve 890a' about axis 890b'. One skilled in the art would understand that other cylindrical valve constructions could be used.

Fig. 9A also depicts a nozzle assembly 872' having asymmetric nozzle ports 907a' and 907b' configured to minimize the amount of fuel/air mixture impinging on the axially rear wall of liner 840. That is, the configuration of the flow directing surfaces 901a' and 901b' of nozzle end cap 872a' are configured to admit the fuel/air mixture into combustion zone 854 predominantly in the tangential direction with respect to axis 842 of the combustion chamber while still admitting some of the fuel/air mixture into other regions generally parallel to chamber axis 842 (i.e., to the right and left of the venturi axis 874 in

Fig. 9A). This asymmetric nozzle port arrangement permits more effective utilization of the combustion volume in the combustion zone while minimizing fuel/air mixture impingement on the liner wall, which can lead to carbon build up, uneven heat transfer, and increased thermal stress-caused distortions.

Fig. 9B is a modification of the construction shown in Fig. 9A with the cylindrical-type air valve 890" spaced a greater distance from the portion of premixer housing 862 supporting the venturi mixing tube 868. It is expected that spacing air valve 890" a greater distance from the premixer housing will help reduce the unavoidable asymmetries in the compressed air flow field exiting air valve 890" and allow the compressed air flow to be distributed more evenly in the premixer housing leading to the inlet of venturi mixing tube 868. This will minimize the pressure drop along the air flow path from the air valve to the venturi inlet and allow a higher maximum power level for the engine while maintaining low emission levels.

It should be appreciated that an exit nozzle such as depicted in Figs. 9-11, as well as those constructed according to the present invention as depicted in Figs. 16-19, can be connected to a mixing tube by installation methods known to those skilled in the art. For example, as depicted in Figs. 10 and 11, nozzle assembly 872 may have a flanged connection 915 and attachment locations 917 for connecting the nozzle assembly to a mixing tube having a mating flanged structure. Alternatively, a mixing tube can incorporate the nozzle assembly integrally into its overall structure such as by casting or welding.

With continued reference to Figs. 8 and 9, the mixing tube is connected to the liner so the flow axis of the mixing tube is aligned to generally intersect the liner axis. However,

at least some of the fuel/air mixture flow channels of the exit nozzle are formed to direct fuel/air mixture in the combustion zone in a substantially tangential direction with respect to the liner axis. This radial orientation of the mixing tubes can provide a more precise sliding fit between the mixing tube and the combustor liner because the combustor inlet opening is less elongated. This results in less leakage of compressed cooling air directly into the combustion zone, and less lateral movement and thermal distortion during operation.

Specifically, controlled swirling flow and combustion is provided in combustion zone 854 by orienting nozzle assembly 872 so the fuel/air mixture will flow in a direction generally between liner wall 840a and liner wall 840b. Mixing tube 868 is radially mounted to liner 840 so that mixing tube flow axis 874 generally intersects liner axis 842. It should be appreciated that alignment need not be precise, so long as divided flows of the fuel/air mixture can be directed by nozzle assembly 872 into the combustion chamber without appreciably impinging liner walls 840a and 840b. Although some impingement of liner wall can be expected, it is preferred to minimize the amount of fuel/air mixture impacted on a given surface in order to reduce the amount of carbon deposited on such a surface during the combustion process. Carbon deposits can eventually insulate areas of the liner, causing problems of thermal fatigue and localized overheating of the combustion chamber.

In operation, and with reference to Figs. 8-11, compressed air from plenum 830 is channeled via passageway 882 over the outside surface of liner 840 for cooling liner 840, and particularly portions which surround combustion zone 854. A portion of the compressed air flowing in passageway 882 is admitted to plenum 884 through orifices 885

and then flows to fuel/air premixer assembly 860 via the interconnection between fuel/air premixer housing assembly 862 and plenum 884 as controlled by compressed air valve 890 via controller 894. This portion of the compressed air is essentially all the compressed air used for combustion (except for inadvertent leakage and compressed air that may be used to power an air-blast type fuel nozzle). In mixing tube 868, the compressed air portion is mixed with the fuel from fuel nozzle 864, again possibly with a small additional portion of compressed air if nozzle 864 is a "air-blast" type nozzle, and is directed along the mixing tube axis 874 to nozzle assembly 872, where the fuel/air mixture is divided into paths along channels 901 and accelerated out of ports 907 into combustion zone 854 of combustion chamber 852. By the orientation and sizes of the nozzle assembly ports 907, the designer can control the distribution and direction of the fuel/air mixture within the combustion volume.

After combustion of the fuel/air mixture in zone 854, the hot exhaust gases pass to dilution zone 856 where dilution air from dilution ports 858 reduces the average temperature of the exhaust before it is ducted via channel 850 past vanes 834 to turbine 820 for work-producing expansion.

The control of combustion afforded by combustion system 810 through the complete mixing of the fuel and air outside the combustion chamber in the fuel/air premixer, including complete vaporization of the fuel if liquid fuel is used, together with the control of the fuel/air ratio of the mixture delivered to the combustion chamber by controlling both the fuel flow and the combustion air flow allows for significant reductions in NO_x levels and the levels of unburned fuel and fuel by-products emanating from engine module 812, as

mentioned earlier. Furthermore, the efficient utilization of essentially the total amount of compressed air flow to either combust the fuel or to dilute the exhaust gases upstream of the turbine provides increased efficiency, considerable reduction of peak combustor temperatures resulting in longer life for combustor liners compared to conventional designs.

The predecessor systems described are configured to provide low emissions at all power ratings for high inlet temperature gas turbine applications while keeping variable geometry flow apparatus away from and outside the hot combustor area.

Alternatively, as seen in Fig. 12, another predecessor construction design is illustrated in which a nozzle assembly 972 has a single channel 1001 for directing the flow of fuel/air mixture in a direction that is generally tangential to the combustion chamber axis due to the downwardly sloped surfaces of channel 1001. Nozzle assembly 972 further includes a single port 1007 in flow communication with channel 1001 for distributing fuel/air mixture within combustion chamber 952. Preferably, the total cross-sectional area of port 1007 is about 70-90% of the cross-sectional area of mixing tube 968 (generally indicated at reference point 913) in order to increase the acceleration of the fuel/air mixture delivered into combustion chamber 952.

Although the above descriptions relate to radially mounted mixing tubes which have a nozzle assembly that extends into the combustion chamber, other mixing tube positions and configurations are possible and can be used with the cooled nozzles of the present invention. For example, it should be appreciated that a mixing tube may be connected to the liner so the flow axis of the mixing tube is slightly tangentially aligned to the liner axis.

As such, the mixing tube's exit nozzle or other like structure can be oriented to direct the flow of the fuel/air mixture tangentially into the combustion zone and preferably minimize impingement of flow onto the liner while maintaining a simple geometric configuration at the liner inlet compared to constructions such as depicted, e.g., in Fig. 1B, where venturi axis 74 is substantially tangentially oriented with regard to liner axis 42.

Further, the present invention may be utilized by predecessor can-type combustor systems which were configured to use uncooled nozzles. With reference to Fig. 13, predecessor combustor system 1100 includes a combustion chamber 1112 including combustion zone 1113 defined by combustion chamber liner 1114. Around liner 1114 is disposed, in spaced relation, pressure vessel 1116, which partly functions as a cooling shroud. A premixer assembly 1126 includes an air valve 1128 and a venturi-type mixing tube 1130, a portion of which is disposed outside liner 1114, and a nozzle assembly portion 1132 disposed to deliver a fuel/air mixture within combustion zone 1113 of chamber 1112. Fuel nozzle assembly 1138 mounted in premixer housing 1139 delivers a spray of fuel into a mixing tube inlet region 1131, where it is mixed in mixing tube 1130 with compressed air in an amount partially controlled by valve 1128 that is fed by compressor 1102. As shown in Fig. 13, valve 1128 is a cylindrical-type three-way valve with rotatable sleeve 1128a (although other types of valves are possible) and can direct air to venturi mixing tube 1130 or to secondary dilution ports 1140 in liner 1114 via bypass conduit 1142 and manifold 1144 (as taught earlier in this specification).

Fig. 13A is an enlargement of the portion of Fig. 13 showing air valve 1128 including rotatable sleeve 1128a, which is a circular segment that can act as a seal against about

1/3 of the inner circumference of the valve. Sleeve 1128a can be rotated by an actuator (not shown) about axis from a position totally obscuring the entrance 1142a to bypass conduit 1142 (as shown in solid in Fig. 13A) to a position blocking air flow to venturi mixing tube 1130 via premixer housing 1139 (shown in dotted Fig. 13A), and allowing full bypass flow to secondary dilution ports (not shown).

For engine applications requiring multiple premixers, an air valve can be provided for each can combustor (as shown in Fig. 13A) or for each pair of combustors, such as depicted in the Fig. 14A-14D embodiment (to be discussed infra), and then connected to a common actuator which would move all the valves simultaneously, in the same way as variable stator blades are moved on axial compressors. One skilled in the art thus would be able to design and construct such actuator apparatus.

With continued reference to Fig. 13A, primary dilution ports 1160 receive a portion of the compressed air from compressor 1102 at a point upstream of manifold 1128b of valve 1128. The dilution portion is dependent upon the pressure drops through the respective flow paths as well as the number and sizing of dilution ports 1160, as one skilled in the art would readily understand. The portion of liner 1114 defining combustion zone 1113 is purposefully sealed off from receiving air except through mixing tube 1130 disposed in chamber inlet 1113a in order to maintain control of the fuel/air ratio and provide low emissions. A gap 1130a is provided between mixing tube 1130 and pressure vessel 1116 to pass combustion air sufficient for idle operation.

Nozzle assembly 1132 is depicted as part of mixing tube 1130 and extends into the combustion chamber 1112 at the center of the can-type combustor liner 1114. As further

shown in Fig. 13B, nozzle assembly 1132 has an end plate 1135 with surface convolutions 1135a forming four channels that direct the fuel/air mixture within chamber 1112 through ports 1133, thereby optimizing the available combustion volume. A total of four ports 1133 are depicted as symmetrically arranged about mixing tube axis 1130a but an asymmetric arrangement with fewer or more ports can be used. Preferably still, the collective area at ports 1133 for nozzle assembly 1132 should be between about 70 and 90% of the largest cross-sectional area of the mixing tube 1130 in order to increase the velocity of fuel/air mixture admitted into chamber 1112 through ports 1133. The aforementioned configuration is intended to achieve the benefits described for nozzle assembly 872 of the Fig. 8 embodiment.

Although shown with a three-way valve 1128 that is highly useful in applications requiring high bypass air flow (i.e., past the cooling channels formed by liner 1114 and pressure vessel 1116) during low power applications, can-type combustor system 1100 can be used with a two-way air valve as described elsewhere in this specification. Also, combustor system 1100 is depicted in use with an axial-type engine having axial compressor section 1102 and axial turbine section 1104, the engine axis being shown schematically as 1106 in Fig. 13. Combustor system 1100 using a can-type combustion chamber can be used in engine configurations employing radial and mixed axial-radial type compressors and turbines, as well.

It is also understood that one or more of the combustor systems can be positioned circumferentially about axis 1106 with the hot gas output of each collected and distributed in turbine inlet plenum 1108 providing low emission operation for the engine.

Figs. 14A-14D show another configuration of a gas turbine that could advantageously use combustion apparatus made in accordance with the present invention. Specifically, Fig. 14A shows a sectional view through gas turbine engine 1210 having compressor section 1214 and turbine section 1216 operatively connected for rotation about engine axis 1218. Engine 1210 includes annular combustor chamber 1220, defined by liner 1222, with combustion zone 1224 and dilution zone 1226. Cooling shroud 1228 surrounds liner 1222 to provide flow passageways for convection cooling of liner 1222 particularly in the vicinity of combustion zone 1224. As with the other embodiments discussed previously, combustion zone 1224 is sealed off from the cooling air flowing through passageways 1262 and 1268 (see Fig. 14D) between shroud 1228 and liner 1220. Thus the combustion zone 1224 receives air for combustion essentially only as part of the controlled fuel/air mixture delivered to combustion zone 1224 through premixer assembly 1230 (to be discussed in more detail henceforth) and thus constitutes a "single stage" combustion zone.

With continued reference to Fig. 14A, premixer assembly 1230 includes a pair of premixers 1232 (only one being shown in FIG. 14A) each having a venturi-type mixing tube 1234 positioned to receive fuel from fuel nozzle 1236 and air from premixer housing 1238 through venturi inlet 1240. Each venturi mixing tube 1234 is configured to deliver fuel/air mixture along venturi axis 1242 and through nozzle assembly 1244 into combustion zone 1224. Nozzle assembly 1244, which is the predecessor uncooled construction, has an extension member 1244a and end cap 1244b having its surface contoured to provide channels and ports 1246a, b for distributing the fuel/air mixture within combustion zone

1224, generally at an angle with respect to venturi axis 1242. See Figs. 10 and 11 for examples. Although not seen in Fig. 14A, the ports 1246 also provide a flow direction for the fuel/air mixture that is in opposed directions with respect to axis 1242. Also as seen in Fig. 14A, premixer housing 1238, which surrounds venturi mixing tube 1234 and mounts fuel nozzle 1236, is itself mounted to separable end portion 1250a of engine pressure vessel 1250.

Fig. 14B is a perspective schematic view of an end portion of engine 1210, which provides an understanding and appreciation for the highly advantageous configuration of engine 1210. As seen in Fig. 14B, the pair of premixers 1230 are mounted to the separable pressure vessel end portion 1250a at essentially diametrically opposed positions with respect to axis 1218. Premixer assembly 1230 also includes a single, cylindrical-type air valve 1252 also mounted on pressure vessel end portion 1250a. Air valve 1252 is activated by actuator 1253 to control the flow of compressed air for combustion to both premixers 1232 along air paths through manifold 1254 and a pair of distribution conduits 1256. Distribution conduits 1256 can be of a variety of shapes depending on the space limitations afforded by the balance of the components of the combustion apparatus and the engine. However, they should be configured to provide a minimum pressure drop and present essentially identical flow restriction characteristics. Distribution conduits 1256 are shown with bellows connectors 1258 leading to compressed air inlets 1260 in each of premixers 1232. Also, air valve 1252 is angularly disposed with respect to axis 1218 to be essentially equidistant from each of premixers 1232 to provide a compact arrangement for premixer assembly 1230 and to help ensure equal pressure drops between air valve 1252

and the individual premixers 1232. Although not shown in Fig. 14B, one or both of the distribution conduits 1256 can be purposefully made with a slightly higher or lower flow resistance than the other to allow flow balancing at the time of construction. Alternatively, preset flow restrictors could be used in distribution conduits 1256 to ensure proper flow balancing between the premixers, but such a construction would entail increases in the overall restriction in the compressed air flow path and thus is not presently preferred.

As a consequence of the configuration of premixer assembly 1230 including the mounting of not only premixers 1232 but also air valve 1252 on separable pressure vessel end portion 1250a, the entire premixer assembly 1230 is removable along with pressure vessel end portion 1250a. As best seen in Fig. 14A, upon removal of the turbine exhaust pipe 1262, premixer assembly 1230 can be removed along with pressure vessel end portion 1250a. This ease of assembly/disassembly is a significant advantage for the configuration of the combustion apparatus shown in Figs. 14A-14D.

Importantly, the individual premixers 1232 are oriented and constructed such that the flow axes 1242 of venturi mixing tubes 1240 are both radially disposed and axially inclined with respect to axis 1218. That is, the extensions of venturi axes 1242 intersect or pass in close proximity to engine/combustion chamber axis 1218 while at the same time exhibit angles of significantly less than 90° with respect to axis 1218 as is depicted schematically in Fig. 14B. This orientation effectively utilizes the normally wasted annular space surrounding the turbine exhaust pipe and advantageously provides a smaller overall "envelope" diameter for engine 1210, of importance in applications requiring a minimized axial profile such as in certain aircraft applications. Moreover, the more effective utilization

of the combustion space in combustion zone 1224 may allow the axial length of combustion chamber 1220 to be reduced, while maintaining sufficient residence time in the combustor to reduce CO and NO_x levels to acceptable values. The axial shortening of combustion chamber 1220 has the advantage of reducing the total heat transfer area that must be cooled by passageways 1262 and 1268 (see Fig. 14D). The reduction in the required cooling air flow leads to a more effective use of the available supply of compressed air, particularly in recuperated engine applications when the recuperated return air would be hot.

With reference now to Fig. 14A and to Fig. 14C, which is a cross-section through the air valve 1252 and distribution manifold 1254, the principal combustion air flow path to the premixer assembly can be seen. In particular, air flows from the radial compressor unit 1214 first along the cooling passages 1262 formed between the combustion chamber liner 1222 and the cooling shroud 1228. In the vicinity of the end of the combustion chamber 1220 proximate the single stage combustion zone 1224, a portion of the compressed air flows outward through apertures 1264 in cooling shroud 1228 and is collected in plenum 1266 formed by cooling shroud 1228 and pressure vessel portion 1250a. Apertures 1264 may have any form and number as long as the remaining cooling air has guidance and maintains the correct velocity.

From plenum 1266, the compressed air flows past air valve 1252 and into distribution manifold 1254 where it splits with essentially half going to each of the respective premixers (not shown in FIG. 14C). The remainder portion of the compressed air, that is, the portion not flowing through the apertures 1264, flows to dilution ports 1269

(Fig. 14A) along passageway 1268 along the inner portion of the annular combustion chamber 1220. Because combustion is essentially completed in the vicinity of the dilution zone 1226 where the dilution air is added, the air traveling along passageway 1268 does not undergo combustion but only mixes with the hot combustion products prior to entering nozzle guide vanes 1215 and then turbine unit 1216.

As shown in Fig. 14C, air valve 1252 is a cylindrical-type valve having a rotatable inner cylinder section 1252a that can progressively close off or open flow paths through the air valve under the control of a fuel/air controller (now shown) via actuator 1253 as in previous embodiments. While other types of air valves can be used, such as butterfly valves, etc., cylindrical valves have been found to exhibit more predictable flow characteristics and be less subject to aerodynamic oscillations at a low flow rates and thus are presently preferred. While the cylindrical air valve 1252 shown in Fig. 14C is a "two-way air valve" the configuration could be modified to include a three-way valve used in conjunction with a second set of dilution ports. Such a construction is depicted in dotted lines in Figs. 14A, 14B, and 14C which shows bypass conduit 1270 interconnected with secondary dilution ports 1272 (Fig. 14A) and is similar to the system shown in Fig. 13 at 1144. The benefits and advantages of such a bypass configuration are set forth in U.S. Patent No. 5,924,276 and my provisional application Serial No. 60/038,943 filed March 7, 1997.

Fig. 14D is an enlargement of the premixer cross-section shown in Fig. 14A and shows in more detail certain additional features of the preferred design. Specifically, Fig. 14D shows venturi mixing tube 1234 having cylindrical flange 1280 which defines an

annular opening with premixer housing 1238. This annular opening is configured and sized to pass an amount of compressed air sufficient for operation of engine 1210 at idle conditions. That is, the air flowing through opening 1282 is taken from the same plenum 1266 that supplies air to the premixers through air valve 1252 but bypasses air valve 1252 and thus is not directly controlled by it. This arrangement allows for simplification in the design of air valve 1252 inasmuch as it is not required to pass a minimum amount of air to sustain combustion at idle operation. Opening 1282 can be configured to have predictable and thus easily controlled air flow rates.

Also shown in Fig. 14D is a flow-evening grid 1284 mounted in premixer housing 1238 to surround venturi mixing tube 1234 in the vicinity of inlet 1240. The function of grid 1284 is to redistribute the flow entering premixer housing 1238 via inlet 1260 and to even out other flow asymmetries arising from the structural features of the premixer housing 1238 in order to obtain a more even circumferential inflow into venturi inlet 1240. Grid 1284 can have an array of evenly spaced and dimensioned orifices or the array can be asymmetric in either orifice positioning or orifice dimensions in order to achieve the desired redistribution of the flow about the venturi entrance 1240.

Also depicted in Fig. 14D is a circumferential indent 1222a in combustion liner 1222 which is intended both to retard the axial flow of combustion products in combustor 1220 to gain more residence time and thus lower CO levels, and to strengthen the structure against buckling. Nozzle assembly 1244 can clearly be seen to be asymmetric in terms of the outlet ports 1246a and 1246b formed by the cooperation of nozzle end cap 1244b and extension member 1244a. As discussed previously, the asymmetries in the nozzle exit

ports are intended to allow better distribution of the fuel/air mixture within the volume of the combustion zone while precluding excessive direct impingement of the fuel/air mixture on proximate portions of the combustor liner. That is, exit ports 1246a and 1246b provide fuel/air mixture flows at different angles as well as different directions with respect to venturi axis 1242 and are related to the orientation of the nozzle in the combustion chamber. And, as in the embodiment disclosed in Figs. 8, 9, 9A and 9B, the total exit area of the nozzle exit ports 1246a and 1246b is less than the maximum cross-sectional flow area in venturi-type mixing tube 1234 to provide acceleration through nozzle ports in order to reduce the possibility of "flashbacks" and burning within the venturi mixing tube itself. Generally, the area of the maximum flow area is at the end of the diverging portion of the venturi region.

While a single pair of premixers 1232 is shown in the Fig. 14A-14D embodiment, two or more pairs could be used, each pair feeding an angular sector of the combustion chamber and having a single air valve and respective distribution manifold and distribution conduits located between the associated premixers. In general, particularly for larger engine sizes, it is highly useful to have multiple premixers to provide a substantially even gas velocity distribution in all portions of the combustion zone, to minimize variations in heat transfer to the liner. The shape, location and number of the nozzle ports, such as ports 1246a, b in the Figure 14A-14D embodiment, also can impact on the gas velocity distribution and should be taken into account.

Alternatively, multiple premixers can be used each with an associated air valve and actuator, but with the actuators interconnected, e.g., by a rotating ring to provide uniform

control. A still further alternative uses a single air valve interconnected with multiple premixers via a doughnut-shaped plenum. Such a configuration is depicted schematically in Figs. 15A and 15B which show a longitudinal cross-section and end view, respectively, of engine 1310 having multiple premixers 1312 each with a separate fuel nozzle 1314. A single air valve 1316 controls the flow of combustion air to distribution plenum 1318 which feeds each premixer 1312. The cross-sectional flow areas of plenum 1318 are made large enough so that the pressure drop along the flow paths from valve 1316 to the individual premixers is substantially the same, to ensure balanced flow. Air valve 1316 can be mounted anywhere convenient on the circumference of pressure vessel 1320 and preferably is of the "cylindrical" type discussed in previous embodiments. As seen in Fig. 15A, compressed air flow enters air valve 1316 directly from the compressor (not shown) through passage 1322 between pressure vessel 1320 and cooling shroud 1324 and also from cooling passage 1326 between shroud 1324 and liner 1328 through aperture 1334. Circumferential seal 1330 blocks compressed air flow from passages 1322 and 1326 directly into plenum 1318. Air valve 1316 is a "three-way valve" shunting excess compressed air directly to secondary dilution ports (not shown) via conduit 1332.

Figs. 16-19 present significant and advantageous improvements of the premixers, combustor systems, and engine module configurations shown in Figs. 8-14D which use nozzle assemblies for distributing a premixed fuel/air mixture within a combustion volume. Like the embodiments in Figs. 8-14, the embodiments achieve better utilization of the available combustion zone volume, minimizing heat transfer areas requiring cooling, and promoting overall space savings and engine thermal efficiency. However, the premixer exit

nozzle constructions in Figs. 16-19 (which of course, can be used with other premixer constructions described above besides those depicted in Figs. 8-14) are intended to minimize the effects of unavoidable flashbacks into the premixer mixing tube during idle or low power operation using fixed exit geometry premixer exit nozzle assemblies. Specifically, the premixer exit nozzles of the present invention are configured with one or more cooling channels supplied with compressed air such that the nozzles can tolerate unavoidable combustion within the nozzles during idle, low power, and/or low speed engine operation. Thus, the cooled nozzles of the present invention which can be fabricated from stainless steel are intended as a lower cost, more durable alternative to nozzles fabricated out of materials e.g. ceramics having high temperature flame resistance.

Specifically, one skilled in the art would appreciate that premixer exit nozzles having a fixed flow area ideally would be configured to have a minimum fuel/air mixture exit velocity (i.e., at idle or low power operation) significantly greater than the flame speed in the mixture, to minimize flashbacks, as well as a maximum exit velocity (i.e., at full power operation) less than that which would cause mixture impingement on the combustor liner walls or instabilities in the flame front. However, due to unavoidable variations in the local mixture exit velocity due to e.g. constructional differences, bulk mixture flow rate oscillations, boundary layer effects, etc., a desired margin between the minimum mixture exit velocity and flame speed may not be achievable using fixed flow area nozzle without incurring unacceptably high maximum mixture exit velocities at high power operation.

The embodiments in Figs. 16-19 are configured in accordance with a design philosophy that first provides the desired restraints on the maximum exit velocity to reduce

impingement and flame front instabilities at full power, while accommodating some flashback-induced burning in the premixer mixing tube at idle and possibly low power operation when local mixture velocities may fall below the flame speed of the mixture. Specifically, and in accordance with the present invention, apparatus for combusting fuel with compressed air received from respective sources in a gas turbine engine comprises a combustion chamber defining a combustion volume, and a premixer including a mixing tube operatively connected to the respective sources of fuel and compressed air for providing a premixed fuel/air mixture, the mixing tube including an axis and an exit. The premixer further includes a nozzle cooperating with the mixing tube exit, the nozzle extending into the combustion chamber for distributing the fuel/air mixture within the combustion volume. The nozzle includes one or more cooling channels operatively connected to the compressed air source for receiving compressed air for cooling.

As embodied herein and with initial reference to Fig. 16, combustor apparatus 1610, including single premixer 1612, is shown for supplying a premixed fuel/air mixture to the combustion volume or zone defined by the combustion chamber of a radial gas turbine engine. In the Fig. 16 embodiment, combustion chamber 1614 (only a part of which is shown in the Figure) includes liner 1616 defining an annular combustion volume 1618 similar to the configuration shown in Fig. 9A with premixer 1612 being radially disposed relative to the combustor axis. However, the present invention can also be used with radial engine configurations having the premixer angularly inclined with respect to the combustor axis such as in Fig. 14A as well as axial flow engines using can combustors such as depicted in Fig. 13. Also, multiple premixers can be used.

As embodied herein, premixer 1612 includes housing 1620 and a venturi type mixing tube 1622 mounted in housing 1620 and having an entrance or inlet 1624 disposed to receive fuel from nozzle 1626 which can be an air-blast nozzle as described earlier, and compressed air from plenum space 1628 between engine housing 1630 and cooling shroud 1632. Entrance 1624 includes a rounded lip portion 1624a to prevent flow separation and increase the efficiency of the venturi to provide a well mixed charge. However, other mixing tube shapes and configurations can be used. Mixing tube 1622 also includes exit 1634 and flow axis 1636.

Preferably, combustor 1610 is a single stage combustor with the flow rates of both the fuel and combustion air being controlled, with essentially only convection cooling being employed for the liner portion defining combustion volume/zone 1618 (i.e., no film cooling for reasons given previously). An air valve, such as cylindrical valve 1690 in Fig. 18, is preferably located in a position diametrically (180°) opposed to the position of single premixer 1612, for reasons to be explained hereinafter. Although not shown in Fig. 16, the air valve also would receive combustion air from plenum space 1628 and meter an appropriate amount to premixer 1612 through twin circumferentially extending manifolds 1635, 1637. Also not shown in Fig. 16 is a fuel valve for controlling the fuel flow rate to fuel nozzle 1626 in conjunction with the control of the air valve to achieve a desired fuel/air mixture ratio, as explained previously. In this case, plenum space 1628 also supplies cooling air to the passageway between liner 1632 and shroud 1616 through impingement holes 1633 distributed and sized in accordance with the expected heat load on the liner

portion surrounding combustion zone 1618 as will be explained in more detail in relation to Fig. 18.

With reference again to Fig. 16, combustor apparatus 1610 further includes nozzle 1640 cooperating with mixing tube exit 1634 for distributing the fuel/air mixture within combustion volume 1618. As depicted in Fig. 16, the nozzle is a separate component from the mixing tube attached by an appropriate flanged connection, but a nozzle construction integral with the mixing tube also is contemplated. As embodied herein, nozzle 1640 has a skirt portion 1642 extending from mixing tube exit 1634 along and peripheral to mixing tube axis 1636 with trailing edge 1644 relative to the fuel/air mixture flow direction through mixing tube 1622 (see arrows marked "F"). Nozzle 1640 also has plate portion 1650 attached to stem 1652 which, in turn, is held and positioned on mixing tube axis 1636 by a plurality of struts 1654 attached to skirt 1642 (only two being shown in the Figure). Plate portion 1650 also includes trailing edge 1655. As depicted in the Figure, stem 1652 acts to fixedly space plate portion 1650 from skirt portion 1642 along mixing tube axis 1636 so that respective trailing edges 1644 and 1654 define annular exit flow area 1656 of nozzle 1640.

For reasons explained previously in relation to e.g. Fig. 9, nozzle flow area 1656 which is fixed, preferably is sized to be less than the flow area 1658 at mixing tube exit 1634 to provide a local increase in the mixture velocity through the annular nozzle exit 1660. It is also preferred that plate portion 1650 have a generally conical surface 1662 facing the upstream flow direction to assist in turning the fuel/air mixture to discharge from the annular nozzle exit 1660 at one or more angles β relative to mixture tube axis 1636.

The discharged fuel/air mixture can thereby be directed both tangentially and axially in the depicted annular combustion chamber 1614 to provide more efficient utilization of combustor volume 1618.

Importantly, nozzle 1640 includes one or more cooling channels supplied with compressed air to mitigate the effects of unavoidable flashbacks and burning within nozzle 1640 which is positioned within the combustion volume and which cannot be directly cooled by the combustion air flowing to venturi inlet 1624 like other parts of venturi mixing tube 1622. As embodied in the Figures, cooling channels are provided for both skirt portion 1642 and plate portion 1650, although one or the other may be eliminated based on the expected local heat loading and the possible use of high temperature barrier materials. In the Fig. 16 embodiment, skirt portion 1642 is generally cylindrical in shape and has a double-walled construction with annular space 1664 between walls 1642a and 1642b. Space 1664 thus comprises a generally annular cooling channel for cooling walls 1642a and 1642b using compressed air from plenum space 1628 admitted through orifices 1666. The compressed air exits adjacent skirt trailing edge 1644 after having cooled skirt portion 1642. The cooling provided by the compressed air is, of course, in addition to any cooling accomplished by the fuel/air mixture flowing through the nozzle, and not undergoing combustion in the nozzle, during idle, low power, or low speed operation.

Plate or cone portion 1650 also is constructed as a double-walled member with space 1668 between walls 1650a and 1650b providing a conically shaped channel for carrying compressed air for cooling walls 1650a and 1650b and then exiting adjacent plate trailing edge 1655. Due to its preferred hollow conical shape, plate portion 1650 is

expected to provide recirculation in space 1657 and flame holding and consequently would experience a high heat load during normal operation. Plate portion 1650 thus would be particularly susceptible to damage from burning within the nozzle 1640 without the present invention. As shown in Fig. 16, the cooling channel formed by conical space 1668 is fed by passageway 1670 in stem 1652 which, in turn, receives compressed air from plenum space 1669 provided by manifolds 1635, 1637, through passageways 1672 in struts 1654. The relatively small amount of compressed air for cooling nozzle 1640 (~1-4% of combustion air) is not expected to materially affect the control of the fuel/air ratio in combustion zone 1618.

In the Fig. 16 embodiment, compressed air for cooling plate portion 1650 is taken from plenum space 1669 through orifices 1674 at a location downstream of the air valve and plenum space 1628 and thus downstream of the location of orifices 1666 which feed skirt portion 1642. Fig. 17 depicts an alternate premixer exit nozzle 1740 where cooling channel 1764 in skirt portion 1742 and cooling channel in plate portion 1750 are fed from the same orifices, namely elongated orifices 1766 (see detail Fig. 17A) from compressed air supply plenum 1728. This enables a more simplified construction to be achieved. More importantly the pressure drop available to drive nozzle cooling flow during idle and low power operation is higher in plenum space 1728 (corresponding to space 1628 in Fig. 16) than that provided by manifold 1635 (plenum space 1669 in Fig. 16). In the Fig. 17 embodiment, plate portion 1750 is formed integrally with stem 1752 and is attached to skirt portion 1742 by three angularly spaced struts 1754 only one being shown in the Figure. Struts 1754 have a vane-shape (see detail Fig. 17B) to decrease form loss pressure drop,

but other aerodynamic shapes can be used. As in the Fig. 16 embodiment, struts 1754 are used to both position plate portion 1750 and supply compressed air to conical cooling channel 1768 via stem passageway 1770 and strut passageway 1772. Rib elements can be used to maintain the proper wall-wall spacing in the double-walled skirt portion and the double-walled plate portion in the Fig. 16 and Fig. 17 constructions. Note skirt portion ribs 1780 and plate portion ribs 1782 in Fig. 17.

Although nozzle flow area 1756 depicted in Fig. 17 has a shape that is generally annular and axisymetric with respect to mixing tube axis 1736, other shapes are contemplated, including asymmetric or "wavy" configurations to provide more effective utilization of the combustion volume, as explained in relation to e.g. Fig. 9A. Such a "wavy" flow area configuration is depicted schematically in Figs. 17C and 17D where double-walled plate/cone portion 1750' has an undulating peripheral shape (best seen in Fig. 17C) which together with skirt portion 1742' give rise to a locally asymmetric flow area 1756'. The asymmetric flow area is expected to enhance local mixing at the exit to reduce maximum mixture velocities and provide more efficient utilization of combustion volume.

In the embodiment using the nozzle construction of Fig. 17C and 17D, the nozzle plate as well as the skirt is double walled and cooled by compressed air, thereby allowing the mixture exit velocity to be lowered even below the flame speed of the mixture without the fear that combustion inside the nozzle would cause damage to the nozzle. Furthermore, such cooling would also provide protection of the nozzle structure at higher loads if carbon deposits or other internal irregularities in the flow path within the nozzle cause local eddies or reverse flow which could hold a flame locally. Further, it is expected

that with such a system, impingement to the liner could also be reduced by 20 to 40% compared to an uncooled nozzle.

Moreover, because the annular, cooled nozzle of the premixer has a "wavy" configuration, for example, by forming peripheral bumps or cusps in the plate/cone portion 1750' at the outer edge, this would act as a combined ejector/mixer and draw surrounding combustion products (single arrows) into the nozzle exit jet stream (double arrow) and lower the velocity further. Thus, the "wavy" configuration would reduce the distance from the nozzle exit to the flame front so that at rated power the combustion volume would be better utilized and/or the heat load on the liner reduced. These constructions also will provide added flexibility in the positioning of one or more premixers within the annular combustion volume.

Fig. 18 shows the exit nozzle construction of Fig. 17 used with a preferred single premixer, single air valve engine configuration as in Fig. 16. In the Fig. 18 embodiment, the fuel/air premixer 1612 receives compressed air from the gas turbine engine compressor (not shown in Fig. 18) via cylindrical air valve 1690 and manifolds 1635, 1637. Manifolds 1635,1637 can be separate conduits or, as shown in Figs. 16 and 18, be formed from members cooperating with the outside surface of pressure vessel 1630. As depicted in Fig. 18, the air from the compressor flows generally axially (depicted schematically by arrow heads) between pressure vessel 1630 and cooling shroud 1632. Thereafter, a portion of the compressed air flows through impingement cooling holes 1633 and then axially (arrow tails) toward the dilution ports (also not shown), while the balance flows circumferentially to air valve 1690.

While a pair of manifolds such as 1635 and 1637 in Figs. 16 and 18 should ordinarily provide an even distribution of compressed air flow to premixer 1612, restrictor plates can be used in one or the other manifold adjacent the premixer to adjust flow distribution and optimize engine performance if needed. Due to the depicted construction, these portions of the overall compressed air flow path are readily accessible affording relative ease of adjustment using such restrictor plates.

While depicted in Fig. 18 as a "two-way" air valve, air valve 1690 can be configured as a three-way valve which can divert the portion of compressed air not required for combustion or impingement cooling directly to a second set of dilution ports (not shown) thereby bypassing the normal flow path for coolant air, namely axially, between combustor liner 1616 and cooling shroud 1632 to the primary dilution ports (also not shown). A full explanation of the benefits and advantages of such a configuration is set forth in the discussion of combustor systems such as shown in Figs. 13A-13C.

The particular air valve and premixer configuration and orientation shown in Figs. 16 and 18 has a further advantage. With reference to Fig. 18, the upper half 1618a of combustion zone 1618 in annual combustor 1614 provides most of the reaction zone where combustion of fuel and air take place while the lower half 1618b functions more like a transition duct to the radial turbine (not shown) for the exhaust gases. The cooling of combustor 1614 is designed according to this requirement, including the location, number, and sizing of impingement cooling holes 1633. Note schematic comparative length of radial arrows 1692 which generally show increased overall impingement cooling flow in the upper 180° sector versus the lower (left side depicted only). At full power, more than 30%

of the engine air mass flow is used to cool the top half of the combustor, while only about 20% is required for bottom half cooling. The premixer mass flow accounts for about 45% of the air mass flow, and about 5% is required for hot section cooling under these conditions. Extracting the air from the bottom half 1618b of the combustor to supply the premixer provides a more optimal split for the following reasons.

First, a smaller amount of air has to be diverted than if the valve was at the top. Because the compressor delivers the air uniformly distributed to the engine housing/pressure vessel 1630 surrounding cooling shroud 1632, only about 15% (20% + 45% - 50%) of air has to flow from the top to the bottom half of the engine around the combustor in the case of a top premixer and a bottom air valve placement. In the case of a top air valve <u>and</u> top premixer arrangement, about 25% (30% + 45% - 50%) of air would have to displaced from the lower half of the engine to the upper half. The available flow areas are thus utilized more efficiently and available pressure drop is conserved with a bottom air valve arrangement, because average velocities and therefore pressure losses are decreased.

The second reason for placing the valve at the bottom in the Fig. 16 and 18 embodiments is that the air traveling to the air valve experiences a static pressure depression according to the equation $\rho + \frac{1}{2} \rho v^2 = CONSTANT$. As the static pressure between pressure vessel and cooling liner is decreased, the pressure differential across the cooling shroud liner decreases as well resulting in a decreased cooling mass air flow rate through a fixed size impingement cooling hole. Close to the valve, the amount and thus velocity of air traveling towards the valve is the highest, resulting in the lowest static

pressure and lowest impingement cooling flow. However, the impingement cooling flow decreases where less cooling is required if the reaction zone is at the top. Therefore it is advantageous to extract the premixer air in a zone of low cooling requirements, i.e., at the bottom of the engine in the configuration depicted in Figs. 16 and 18.

In summary, extracting the premixer air from the region of the pressure vessel remote from the premixer exit is beneficial because:

1. Less air has to be displaced within the engine;
2. The biggest decrease in static pressure occurs where there is the least cooling required.

While the use of ceramic materials for the premixer nozzle is not ordinarily preferred because of lack of ductility, it may nonetheless be prudent to use ceramic for certain nozzle components in some applications to provide additional resistance to burnout due to flame holding within the nozzle as a consequence of the build up of carbon deposits. Figs. 19, 19A, and 19B depict gas turbine engine combustion apparatus having a premixer with such a "hybrid" nozzle embodiment of the present invention including a metallic skirt portion 1942 and a ceramic plate or cone portion 1950 which, together with skirt portion 1942, defines the nozzle exit flow area 1956 as in the previously discussed embodiments. Premixer housing 1920 can be fed from an air valve (not shown) via one or more manifolds 1635 as discussed in relation to the embodiment shown in Fig. 18. Also, perforations 1917 and 1919 in combustion lines 1916 are for a torch assembly and ignitor, respectively, which could be provided to achieve light-off.

Specifically, premixer 1912 in Fig. 19 includes nozzle 1940 having skirt portion 1942 which extends past pressure vessel 1930, cooling shroud 1932, and combustion liner 1916 into the combustion space or volume 1918. A small gap 1932a can be provided in cooling shroud 1932 adjacent skirt 1942 to provide convection cooling. Skirt portion 1942 which is generally cylindrical, can be made of stainless steel and can include a plurality of through-holes 1980 which are shown dotted in Figs. 19 and 19A and constitute internal cooling channels for skirt portion 1942. Through-holes 1980 would be angled and configured to provide effusion cooling of skirt portion 1942 proximate skirt trailing edge 1944, although other channel configurations are possible. Through-holes 1980 can be fed from the compressed air in the passageway between cooling shroud 1932 and combustion liner 1916, due to the low cooling requirements for the depicted skirt construction. If additional cooling is required, through-holes 1980 could be fed from the higher pressure compressed air source in plenum 1928 between pressure vessel 1930 and cooling shroud 1932 such as e.g., by suitable passageways (not shown) with the wall of skirt 1942.

As depicted in Fig. 19, nozzle plate portion 1950 is generally conical in shape and is formed from a ceramic material which preferably includes dispersed ceramic fibers to ensure integrity if cracking should develop during prolonged engine operation. It is expected that ceramic nozzle plate portion 1950 would be fabricated by casting and then sintering. While shrinking may occur during sintering, those skilled in the art of fabricating complex ceramic shapes would be able to select appropriate "green" casting dimensions to yield near-net final (sintered) shapes without undue experimentation. Appropriate finishing can be used to provide desired final dimensions and shapes.

With continued reference to Fig. 19, ceramic plate portion 1950 is mounted to skirt portion 1942 by an assembly including a plurality of hollow, vane struts 1954 (see Fig. 19B), metal cap 1982, metal sleeve 1983 operatively connected to struts 1954 and a through-bolt 1984 which captures ceramic plate portion 1950 to metal sleeve 1983 via cap 1982. Metal spacer 1985 can be provided to provide a desired insertion depth of plate portion 1950, and thus value of flow area 1956. Spring 1981 can be included to accommodate different thermal expansion coefficients of ceramic plate portion 1950 and metal bolt 1984.

Bolt 1984 and the truncated vertex 1986 of conical ceramic plate portion 1950 lie approximately on axis 1936 of premixer venturi 1922, as in previous embodiments. Bolt 1984 has cooling channel 1988 which is fed compressed air from passageways 1972 in hollow struts 1954 via ports 1988a. Struts 1954 have a vane shape similar to struts 1754 in Fig. 17B and, optionally, have cooling holes 1992 (shown dotted in Fig. 19A) on the trailing edges to discourage flame holding. As depicted in Fig. 19, strut passageways 1972 receive compressed air from plenum space 1928 between cooling shroud 1932 and pressure vessel 1930 via orifices 1990.

As in the previous embodiments of the present invention, plate portion 1950 is provided with a hollow recessed region 1994 to encourage recirculation of combustion products from combustion volume 1918 in the vicinity of nozzle 1940 to promote flame holding outside the nozzle. Also, as in the Fig. 17C and 17D embodiment, the trailing edge 1955 of the plate portion is made "wavy" or undulating in the peripheral direction, with alternating crests 1996 and troughs 1998. Troughs 1998 provide port-like flow paths for

the fuel/air mixture (double arrow) and can be configured to provide flow asymmetry in the peripheral direction if desired, such as for reasons given previously in relation to the predecessor, uncooled nozzles depicted e.g. in Fig. 14A. Crests 1996 provide channels or passageways 1997 (single arrow) connecting the recessed region 1994 with the vicinity of nozzle exit area 1956 to allow combustion products to be drawn into the fuel/air streams to more quickly slow down the stream velocities. This encourages stable burning outside the nozzle during high power operation and lessens the tendency for impingement on liner 1916.

Due to the use of ceramic plate member, the overall amount of cooling air for the nozzle can be decreased. The amount of cooling air that is admitted directly to the combustion volume via exit 1988b of channel 1988 in bolt 1984 (see Fig. 19A) would be small and would not be expected to locally quench combustion. The cooling air exiting through-holes 1980 in skirt portion 1942 and optional channels 1992 in struts 1954, exits within nozzle 1940 and can mix with the fuel/air mixture before discharge into combustion zone 1918.

With the above detailed description of the combustor system and fuel/air premixer apparatus and method of operating same of the present invention, those skilled in the art would appreciate that modifications may be made to the invention without departing from its spirit. Therefore, it is not intended that the scope of the invention be limited to the specific embodiments illustrated and described above. Rather, it is intended that the scope of this invention be determined by the appended claims and their equivalents.

WHAT IS CLAIMED IS:

1. Apparatus for combusting fuel with compressed air received from respective sources in a gas turbine engine, the apparatus comprising:

a combustion chamber defining a combustion volume;

one or more premixers each including a mixing tube operatively connected to the respective sources of fuel and compressed air for providing a premixed fuel/air mixture, the mixing tube including an axis and an exit,

wherein the premixer further includes a nozzle cooperating with the mixing tube exit, the nozzle extending into the combustion chamber for discharging the fuel/air mixture within the combustion volume, and

wherein the nozzle includes one or more cooling channels operatively connected to the compressed air source for receiving compressed air for cooling.

2. The apparatus as in claim 1 wherein the combustion chamber is annular and has an axis, wherein the nozzle extends at least partially into the combustion volume and distributes at least a portion of the fuel/air mixture within the combustion volume tangentially with respect to the chamber axis.

3. The apparatus as in claim 1 wherein the nozzle has an exit flow area, and wherein the nozzle exit flow area is less than a mixing tube exit flow area whereby the fuel/air mixture is accelerated through the nozzle exit.

4. The apparatus as in claim 1 wherein the combustion chamber is a single stage combustion chamber with the combustion volume substantially sealed off from the

compressed air source except for compressed air that is discharged from the nozzle cooling channel and the compressed air that is part of the fuel/air mixture discharged from the mixing tube.

5. The apparatus as in claim 1 wherein the nozzle includes a skirt portion extending from the mixing tube exit peripheral to the mixing tube axis, and a plate portion positioned on the mixing tube axis, the skirt portion and plate portion cooperating to define a nozzle exit flow area.

6. The apparatus as in claim 5 wherein the nozzle plate portion is supported by at least one strut with a compressed air passageway, the cooling channel being interconnected to the compressed air source through the strut passageway.

7. The apparatus as in claim 6 wherein the plate portion is substantially conical with a cone vertex positioned on the mixing tube axis and directed upstream relative to a fuel/air mixture flow path, and wherein the conical plate portion has a double-walled construction, the walls being spaced apart to define the cooling channel.

8. The apparatus as in claim 5 wherein the skirt portion is generally cylindrical and has a double-walled construction, the walls being spaced apart to define the cooling channel.

9. The apparatus as in claim 5 wherein both the skirt portion and the plate portion have respective cooling channels.

10. The apparatus as in claim 9 wherein the plate portion and the skirt portion have respective trailing edges relative to a flow path of the fuel/air mixture, the respective cooling channel exits being positioned adjacent the respective trailing edges.

11. The apparatus as in claim 5 wherein the plate portion is formed of a ceramic material.

12. The apparatus as in claim 11 wherein the plate portion is generally conical in shape and has a vertex directed upstream relative to a fuel/air mixture flow direction.

13. The apparatus as in claim 11 wherein the ceramic plate portion is supported by at least one strut having a passageway interconnected with the compressed air source.

14. The apparatus as in claim 13 wherein the ceramic plate portion is connected to the strut by a bolt member, and wherein the bolt member includes a cooling channel operatively interconnected with the strut compressed air passageway.

15. The apparatus as in claim 13 wherein the strut is vane shaped and wherein one or more vane cooling channels interconnected to the compressed air passageway are provided in a vane trailing edge.

16. The apparatus as in claim 11 wherein the skirt portion includes a plurality of cooling channels configured to provide effusion cooling.

17. The apparatus as in claim 5 wherein said plate portion is configured to enhance mixing of combustion products in the combustion volume with the fuel/air mixture being discharged through the nozzle exit flow area, whereby the velocity of the fuel/air mixture can be reduced.

18. The apparatus as in claim 5 wherein the plate portion has a recess adjacent the nozzle exit flow area and facing the combustion volume for promoting recirculation of combustion products.

19. The apparatus as in claim 18 wherein said plate portion trailing edge has a wavy shape with alternating crests and troughs in a peripheral direction and wherein one or more crests provide a channel communicating the recess with a location proximate the nozzle exit flow area.

20. The apparatus as in claim 1 wherein the apparatus further includes an air valve disposed in a compressed air flow path between the compressed air source and the mixing tube for controlling air flow to the mixing tube, and wherein the cooling channel is flow connected to the compressed air flow path at a point upstream of the air valve.

21. The apparatus as in claim 1, wherein the combustion chamber is annular and has an axis, a liner, and a cooling shroud surrounding and spaced from the liner; wherein the apparatus has only a single one of said premixers disposed at one angular position relative to the combustion chamber axis, a compressed air flow path interconnecting the compressed air source and the mixing tube entrance, a single air valve disposed in said compressed air flow path at a second angular position spaced relative to the combustion chamber axis substantially 180° from the one angular position, and wherein a portion of the compressed air flow path between said one air valve and the premixer mixing tube entrance includes at least one manifold extending in a circumferential direction relative to the combustion chamber axis.

22. The apparatus as in claim 21 including a housing spaced from and surrounding said cooling shroud wherein the space between the cooling shroud and the housing comprises another portion of the compressed air flow path, and wherein said air valve and said nozzle cooling channel are fed from said another portion.

23. The apparatus as in claim 22 wherein impingement cooling holes are provided in said cooling shroud to be supplied from said another portion of said compressed air flow path and directed at said combustion liner, and wherein said cooling holes are sized to provide more impingement cooling air flow in a 180° sector surrounding said one angular position than the impingement cooling air flow in a 180° sector surrounding said second angular position.

24. A gas turbine engine having the apparatus of claim 1.

25. Method of operating a gas turbine engine having a combustor with a fuel/air premixer, the premixer including an exit nozzle having an exit flow area extending at least partially into a combustion volume of the combustor for discharging a fuel/air mixture through a nozzle exit area, the method comprising the steps of:

configuring the exit nozzle to have an exit flow area value to provide a predetermined maximum fuel/air mixture exit velocity at full power conditions;

configuring the exit nozzle to have at least one cooling channel; and

flowing compressed air through the channel for cooling the exit nozzle during gas turbine operation, said one cooling channel being sized such that combustion of the fuel/air mixture within the exit nozzle can be tolerated under operating conditions when a fuel/air mixture velocity within the exit nozzle is below a flame speed of the fuel/air mixture.

26. The method as in claim 25 wherein the exit nozzle configuring step includes configuring the nozzle to provide recirculation of, and mixing of the discharged fuel/air mixture with, combustion products in the combustion volume near the nozzle exit area.

27. Method for controlling the compressed air flow in a radial gas turbine engine to provide cooling and combustion air, the engine having an annular combustion chamber with an external wall convectively cooled by compressed air, a single premixer assembly operatively connected to the combustion chamber for providing a premixed fuel/air mixture for combustion including a nozzle extending into the combustion chamber, the nozzle being cooled by compressed air flowing in one or more channels formed therein, the method comprising the steps of:

configuring a nozzle exit area and orientation to deliver a fuel/air mixture for combustion in a portion of the combustion chamber adjacent the premixer;

providing compressed air flow to a plenum substantially surrounding and radially spaced from the combustion chamber for supplying the cooling and combustion air;

extracting the compressed air substantially from a first region of the plenum opposed to the combustion chamber portion, for supplying combustion air to the premixer; and

extracting compressed air substantially from a second region of the plenum adjacent the combustion chamber portion, for supplying the nozzle cooling channels.

28. A method for controlling the flow of compressed air for cooling, and for combustion with fuel in, a combustion chamber of a gas turbine engine, the combustion chamber being annular and having an axis, a combustion chamber liner defining a combustion volume, and a cooling shroud surrounding and spaced from the combustion chamber liner, the gas turbine engine including a compressor for providing a source of compressed air flow along a path, a fuel conduit connectable to a source of fuel, a

premixer apparatus including a single premixer for providing a fuel/air mixture and having a mixing tube having an entrance in flow communication with the compressed air flow path and the fuel conduit and having an exit in flow communication with the combustion volume through an exit nozzle, at least part of the exit nozzle extending into the combustion volume, and the engine having a housing surrounding and spaced from the shroud, the method comprising the steps:

positioning the single premixer at one angular position relative to the combustion chamber axis;

positioning a single air valve at a second angular position relative to the combustion chamber axis, the second angular position being spaced about 180° from the first angular position;

providing at least one manifold extending in circumferential direction between, and interconnecting, the air valve and the premixer to comprise a portion of the compressed air flow path;

providing one or more cooling channels in the premixer exit nozzle, the cooling channels being flow connected to the space between the housing and the cooling shroud, the space between the housing and the shroud comprising another part of the compressed air flow path;

flowing compressed air from the compressor through said another part of the compressed air path to both the air valve and the nozzle cooling channel; and

using the air valve to control the compressed air flow rate from the air valve through the manifold to the premixer in accordance with a fuel flow rate to achieve a fuel/air mixture with a desired fuel/air ratio.

29. The method as in claim 28 further including providing impingement cooling holes in the cooling shroud directed at the combustion chamber liner, and sizing the cooling holes to provide more impingement cooling air flow through the cooling holes located in a 180° sector surrounding the first angular position relative to the impingement cooling air flow through the cooling holes in the 180° sector surrounding the second angular position.

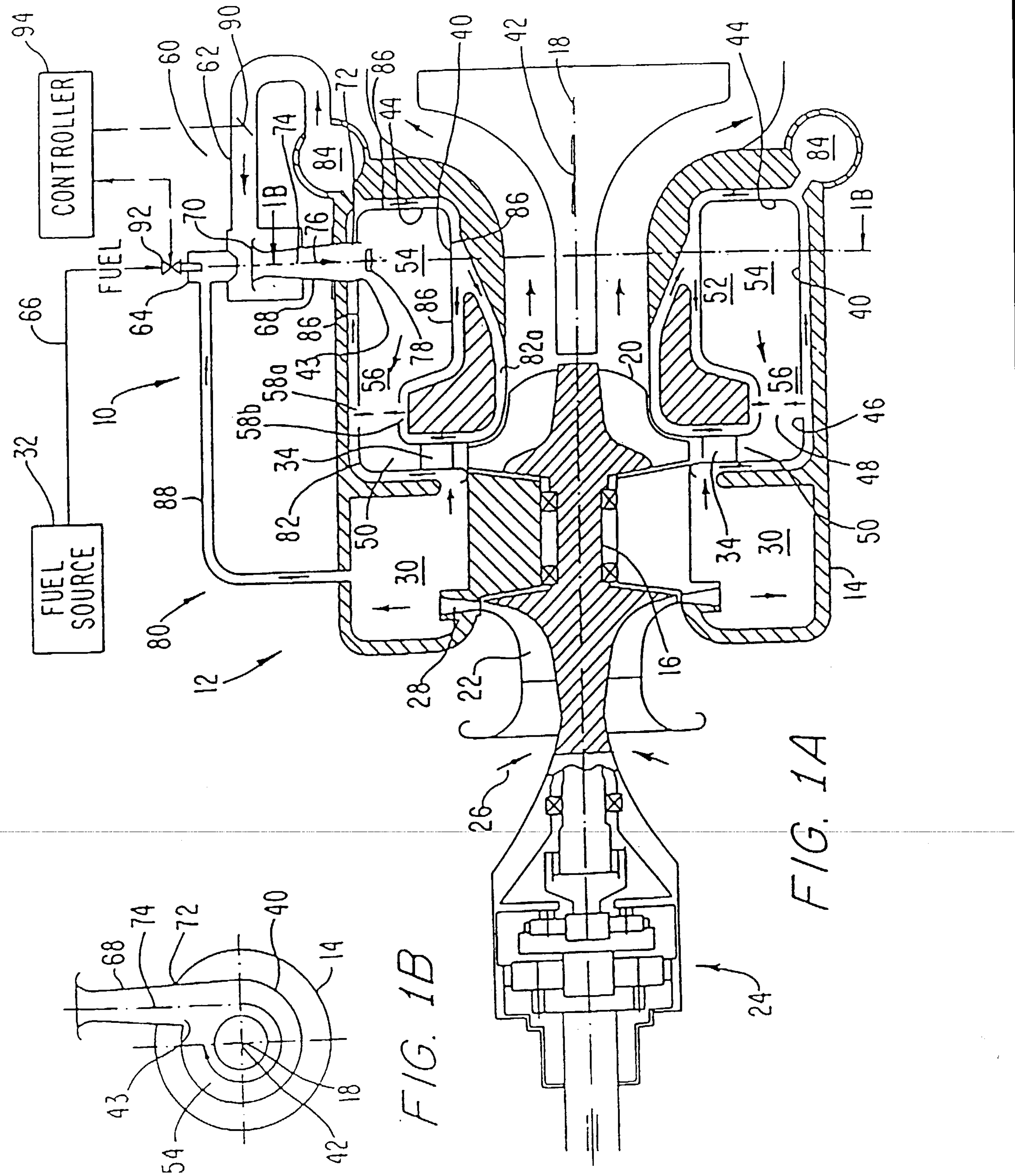

FIG. 1A

FIG. 1B

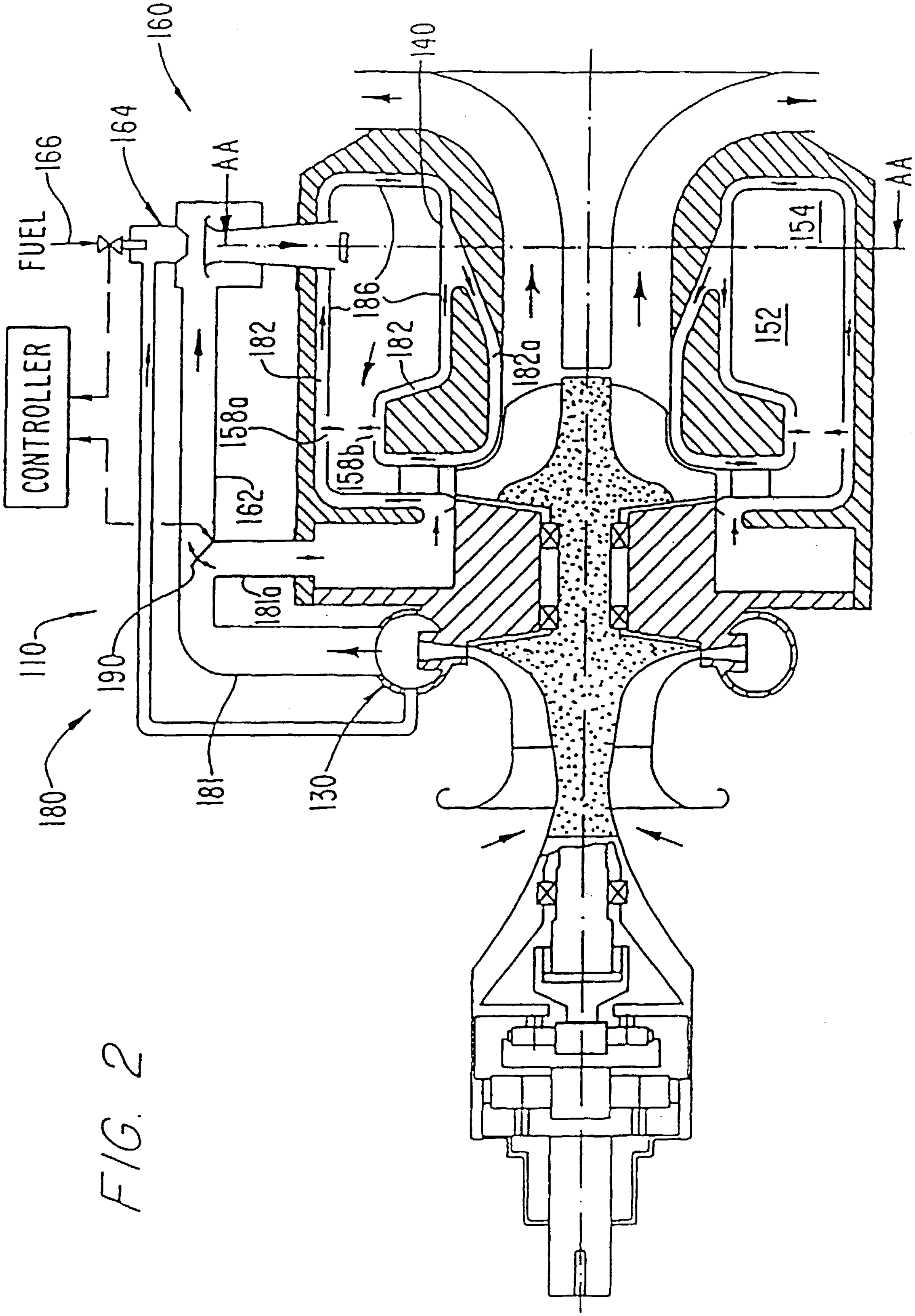
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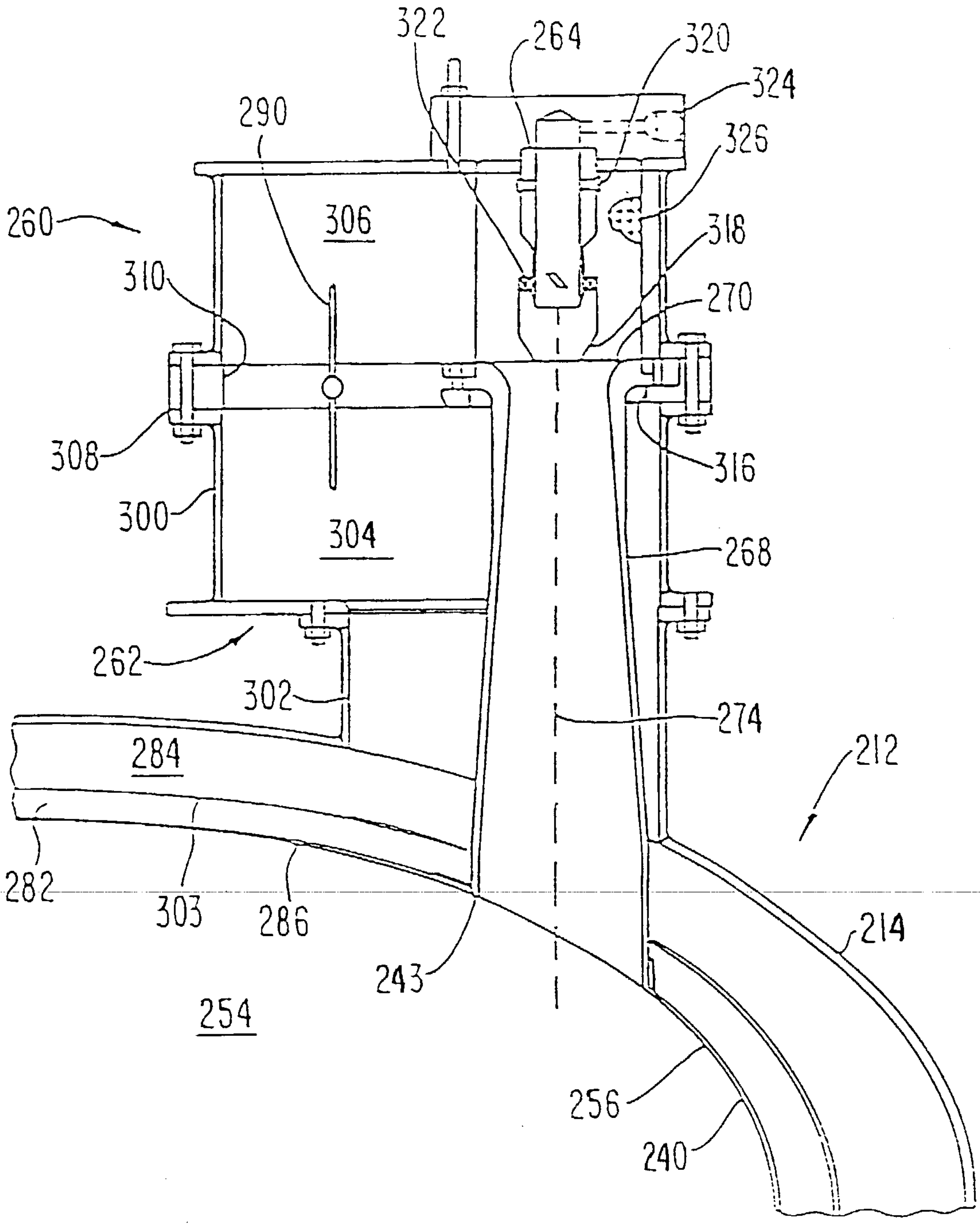
FIG. 2

FIG. 3A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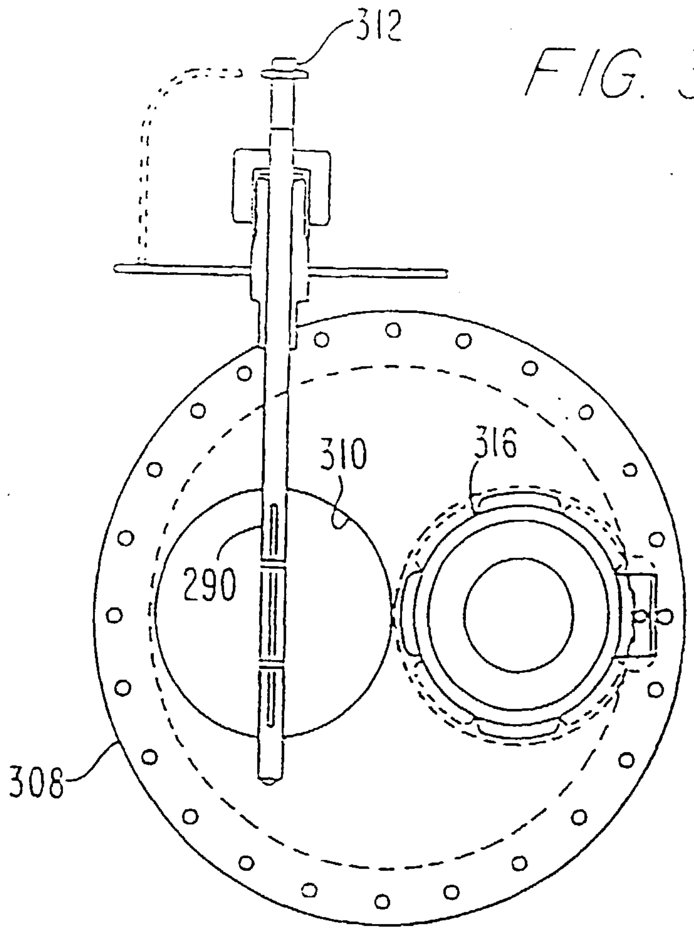


FIG. 3B

FIG. 3C

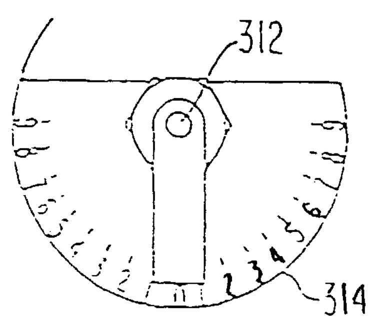
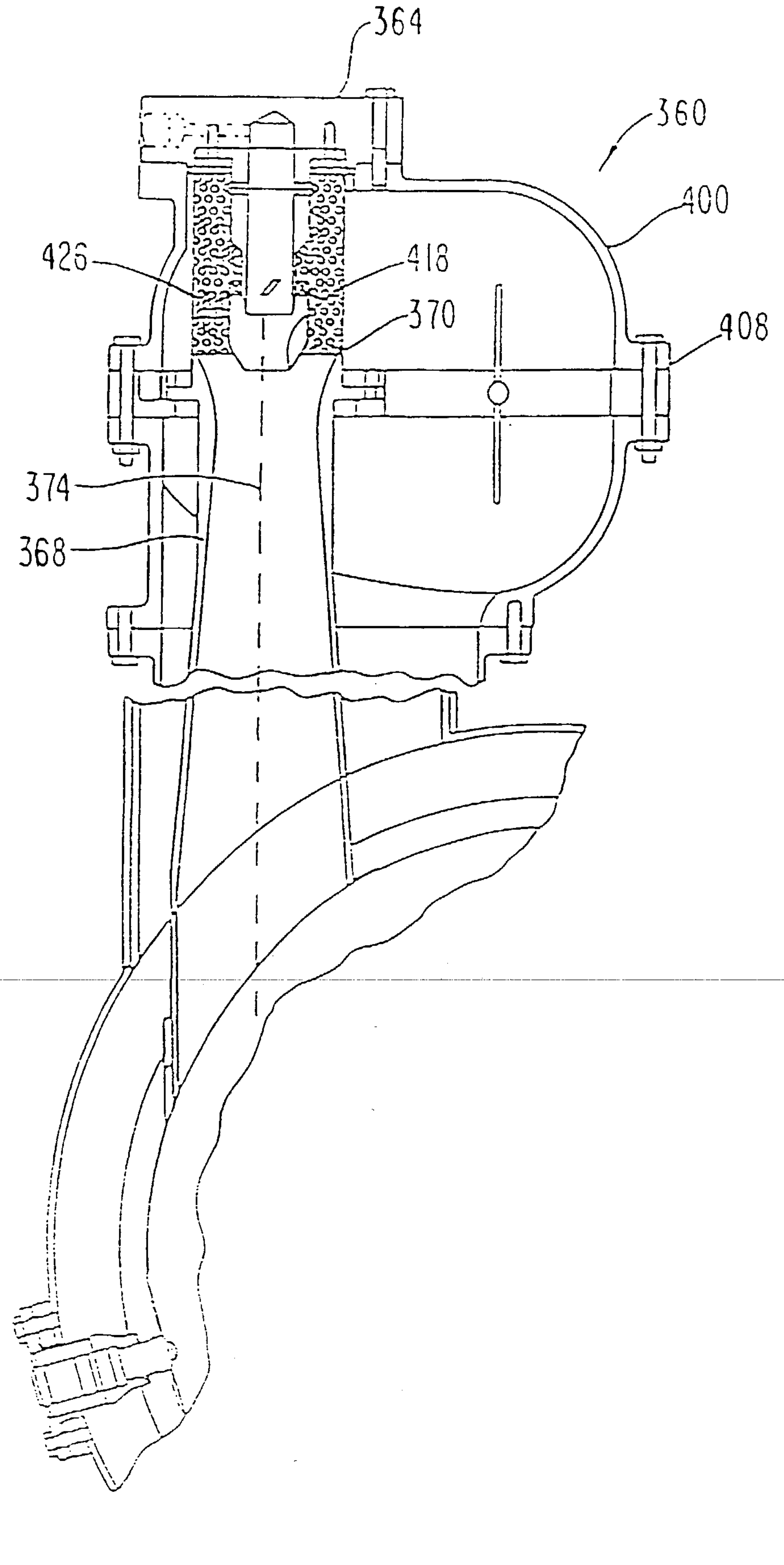


FIG. 4



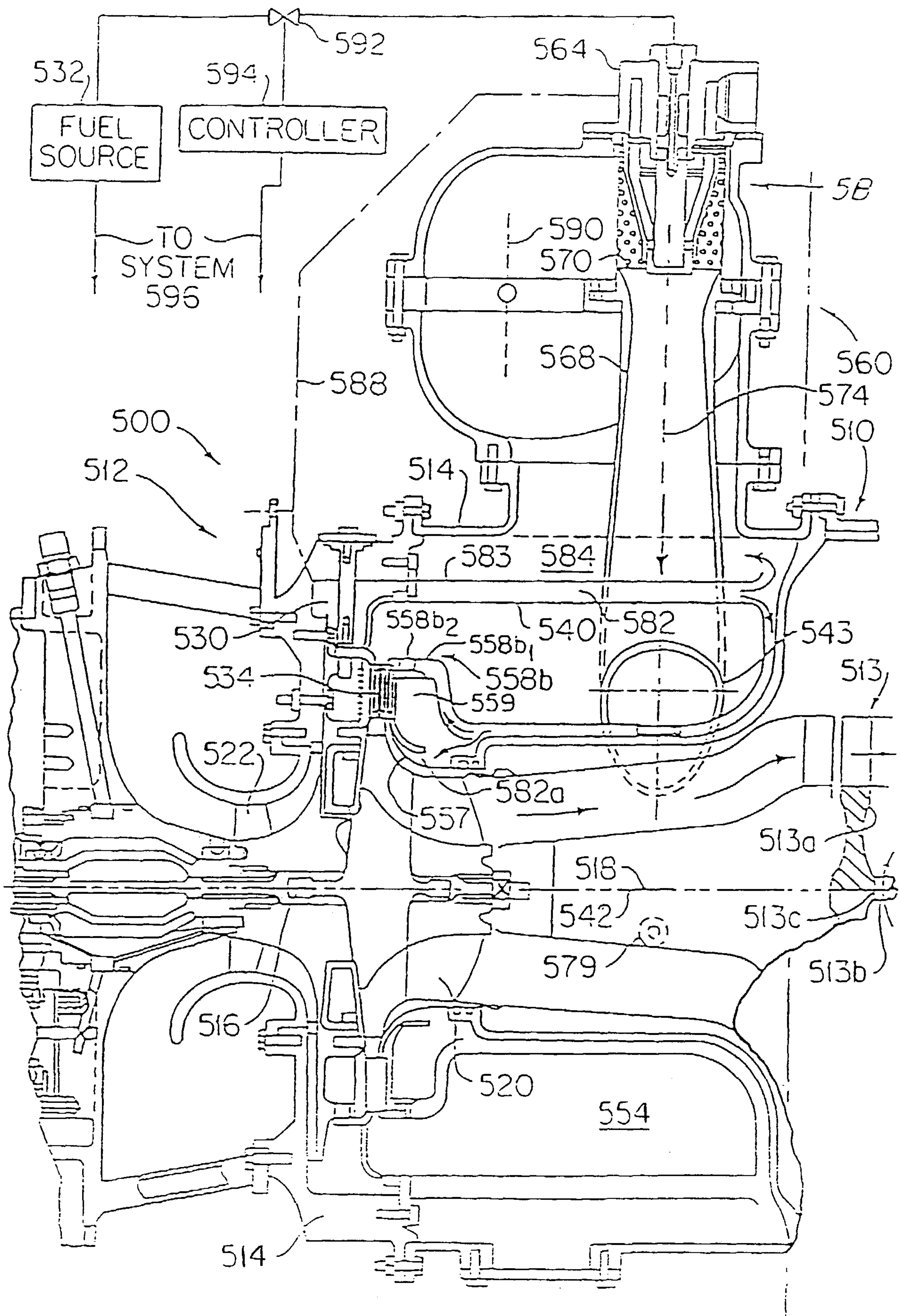

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FIG. 5A

FIG. 5B

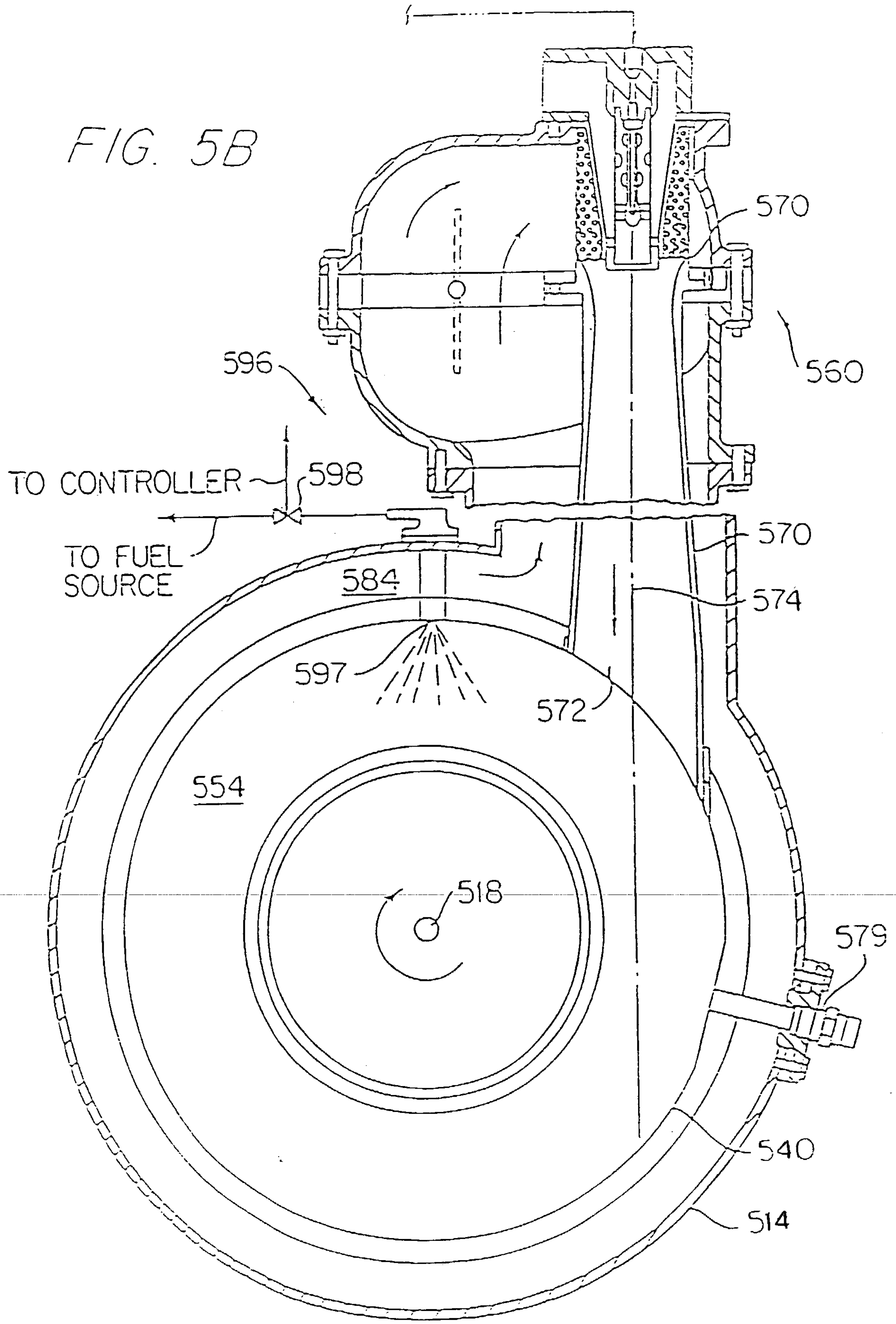
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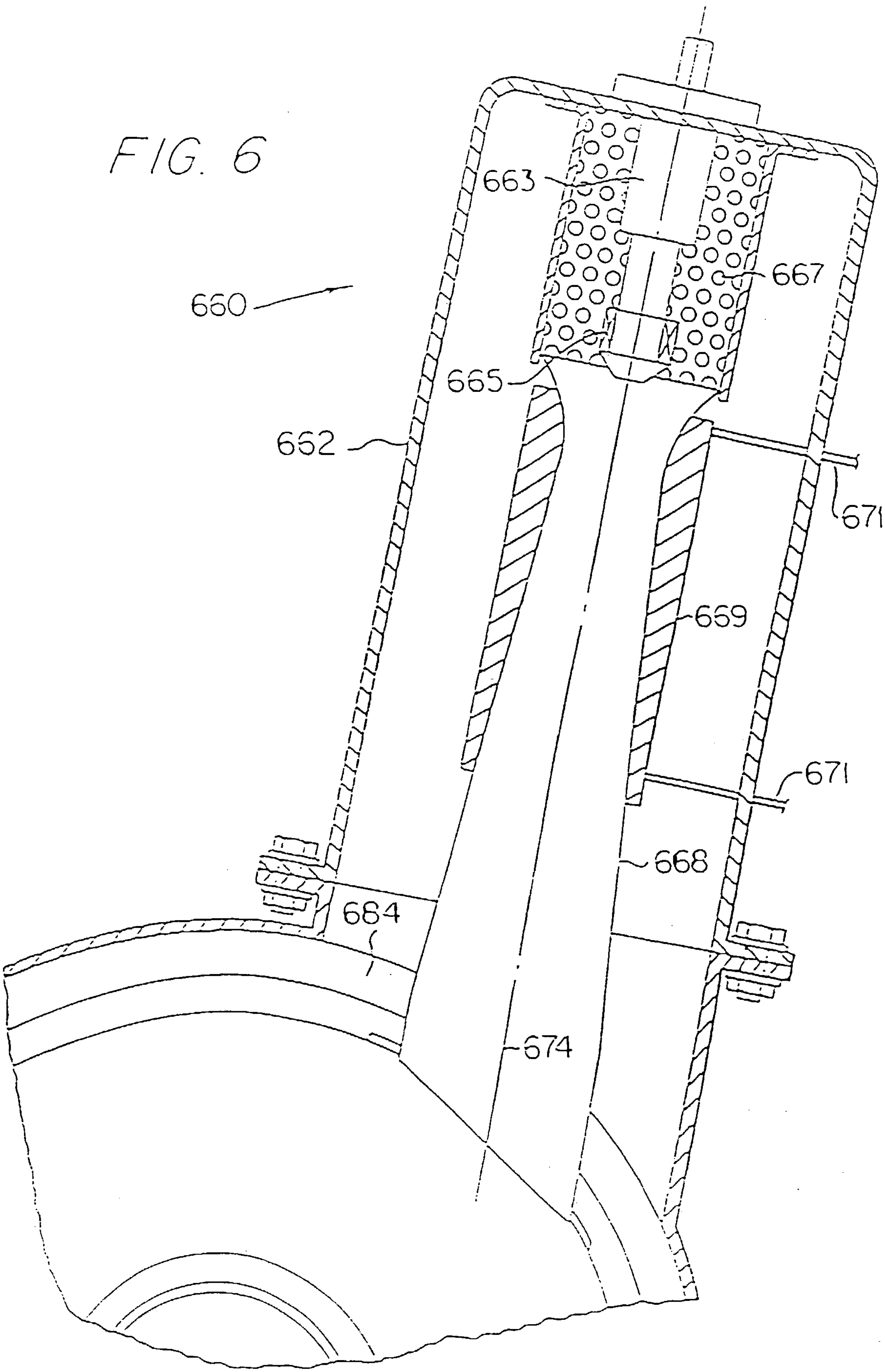
FIG. 6



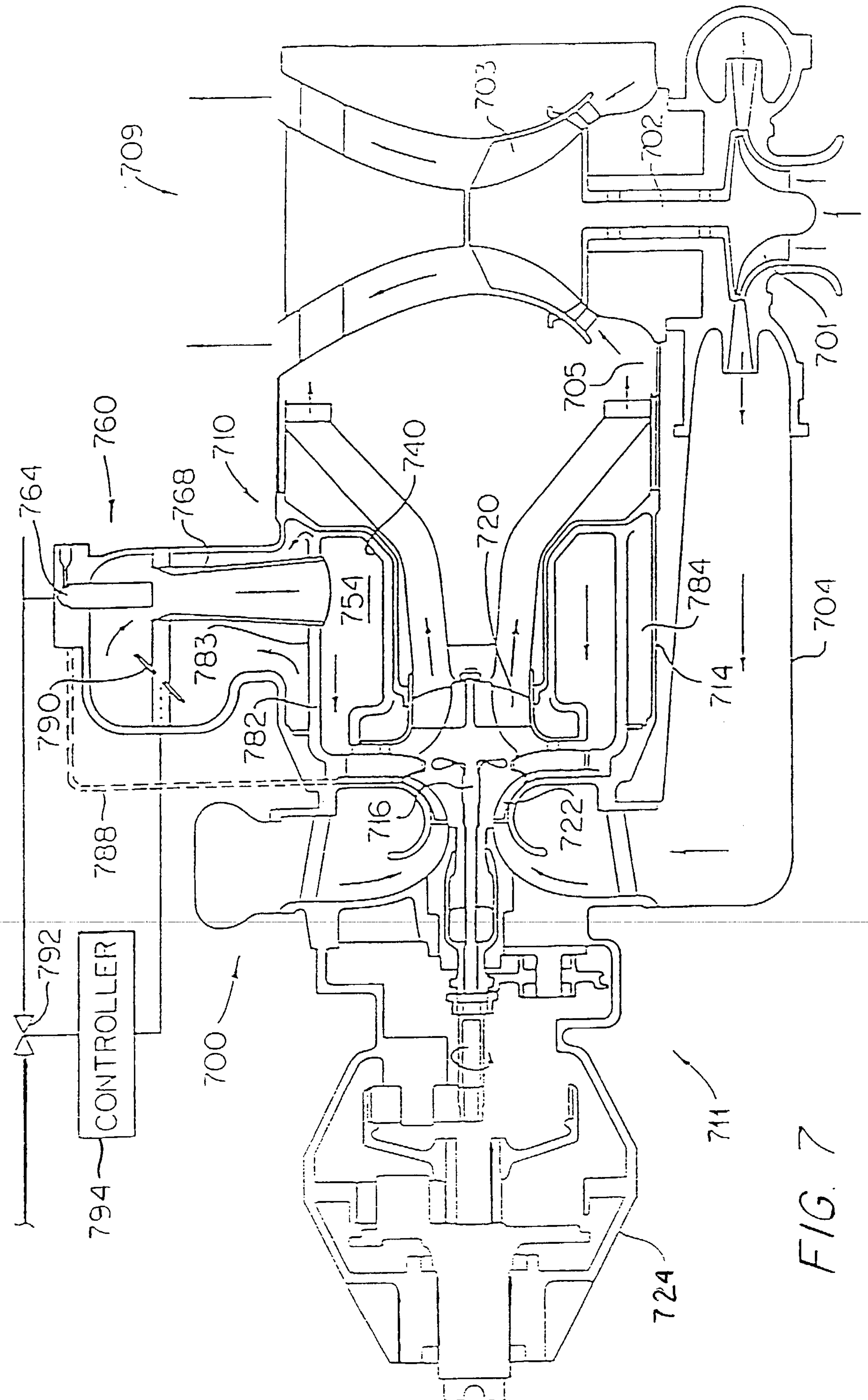

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FIG. 7

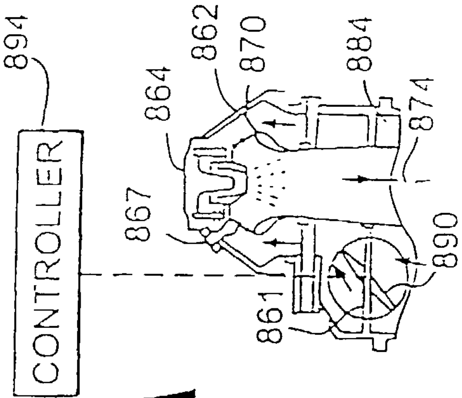
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FIG.8A

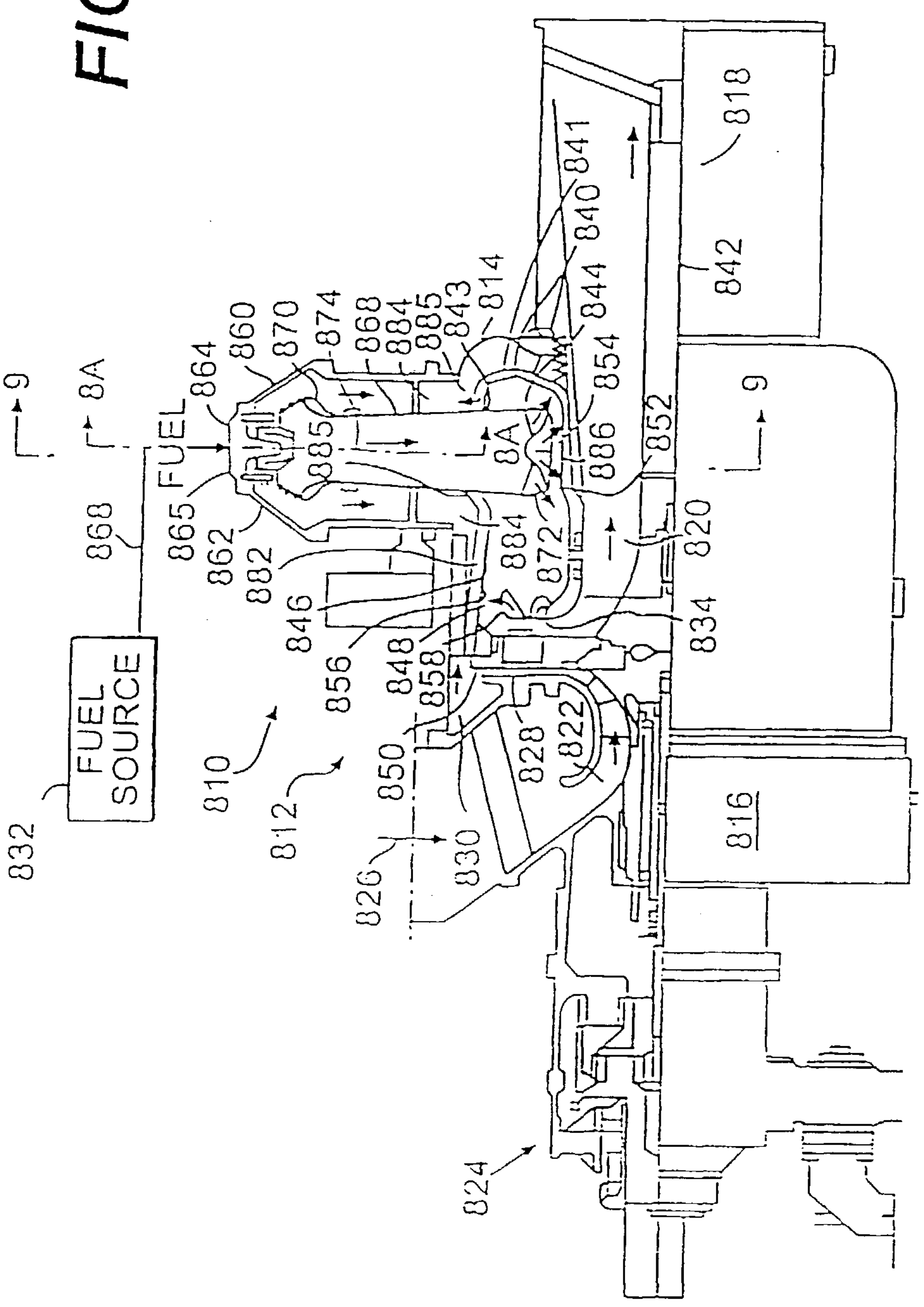
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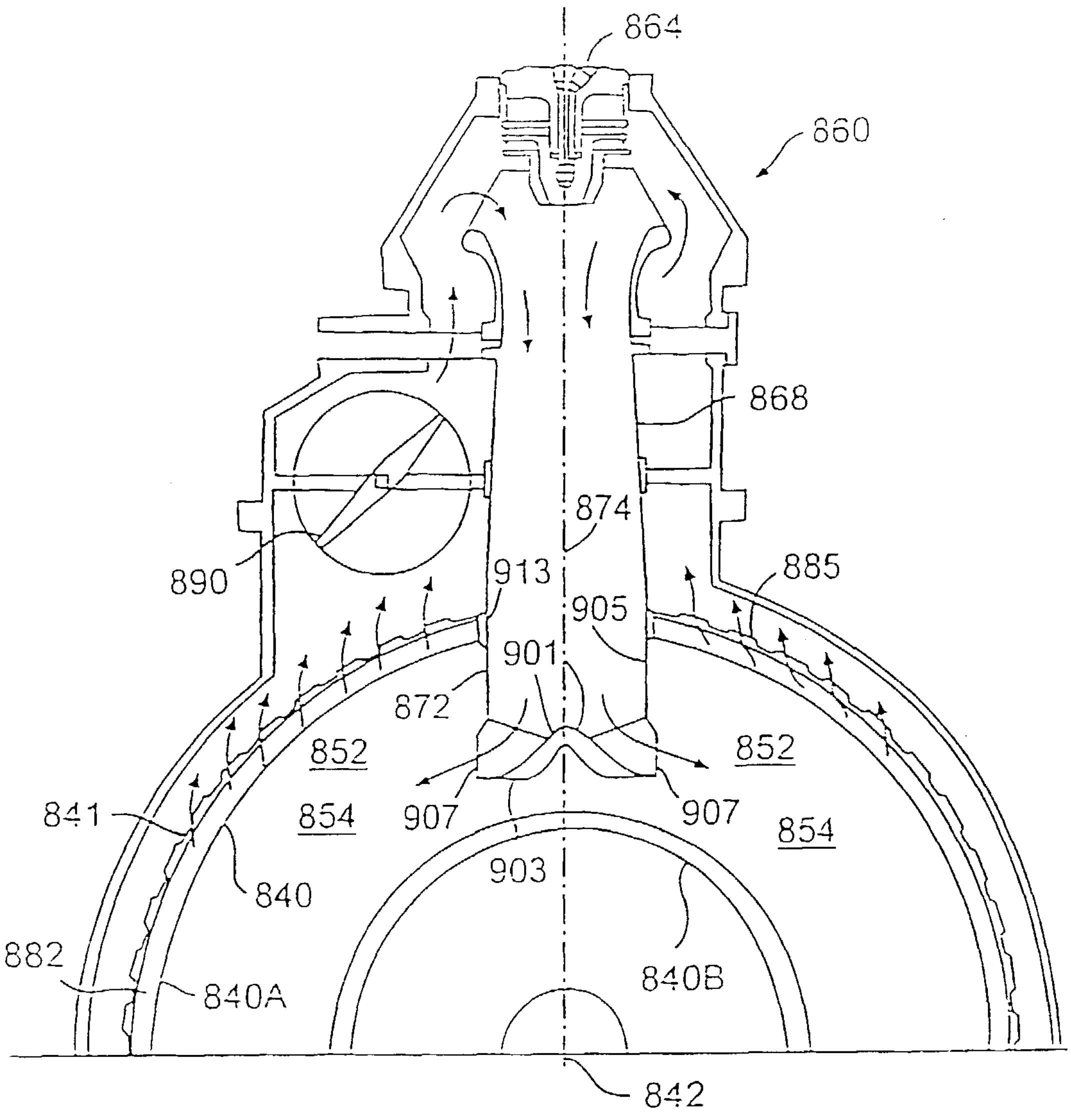
FIG.8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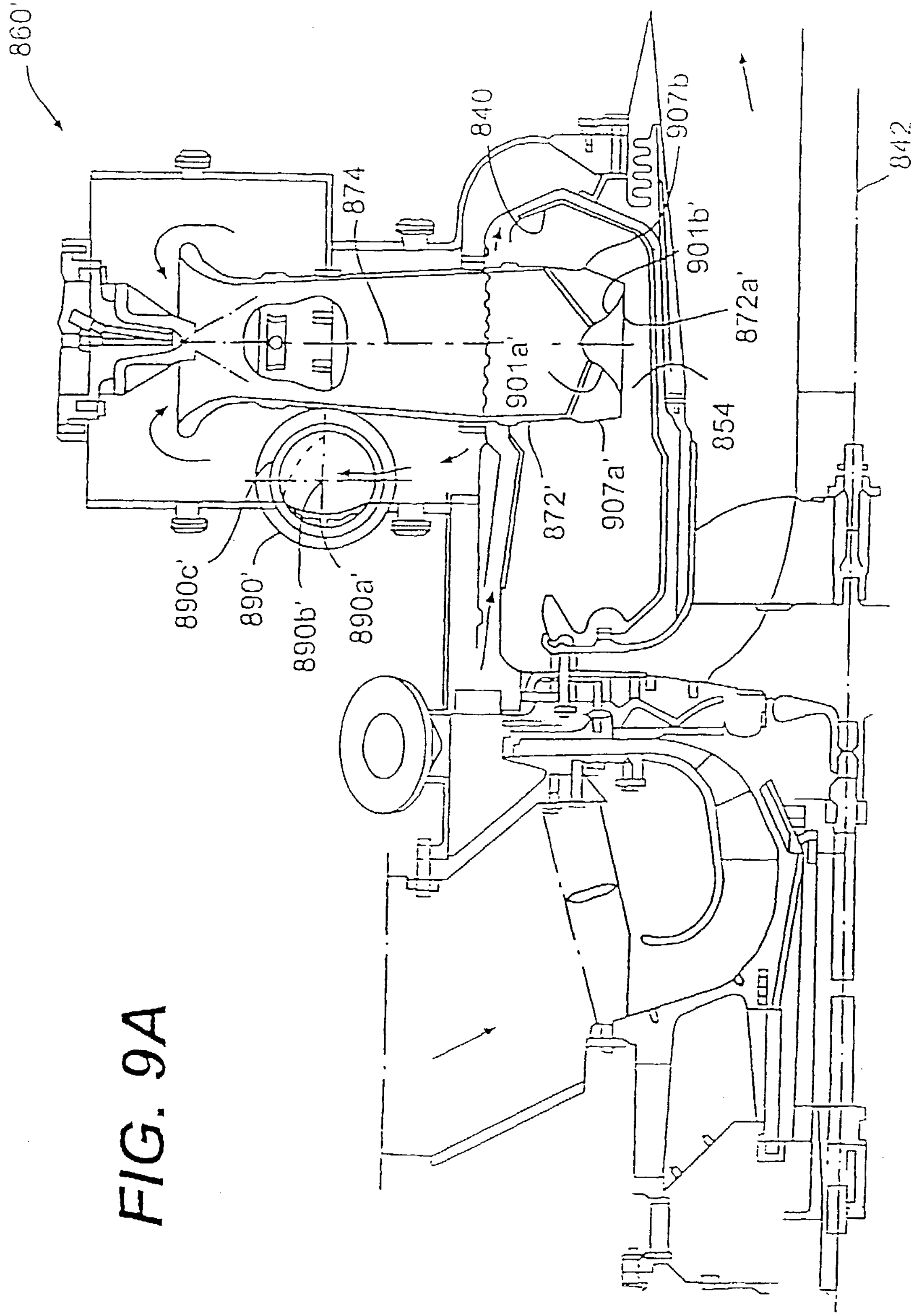
840A
840B
842

FIG.9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840
907b
842
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901b'
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901a'
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907a'
872'
890c'
890'
890b'
890a'

FIG. 9A

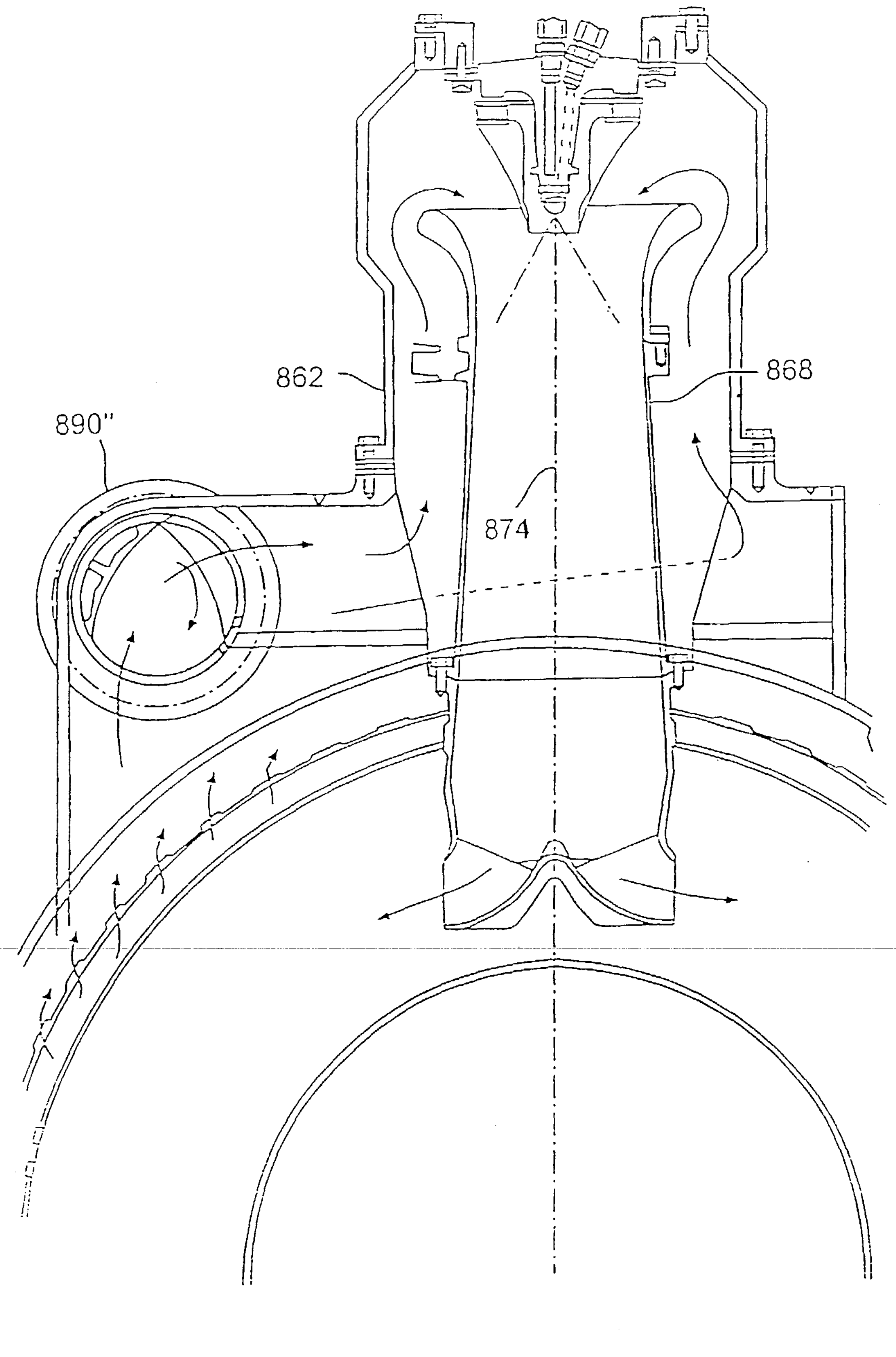

FIG.9B

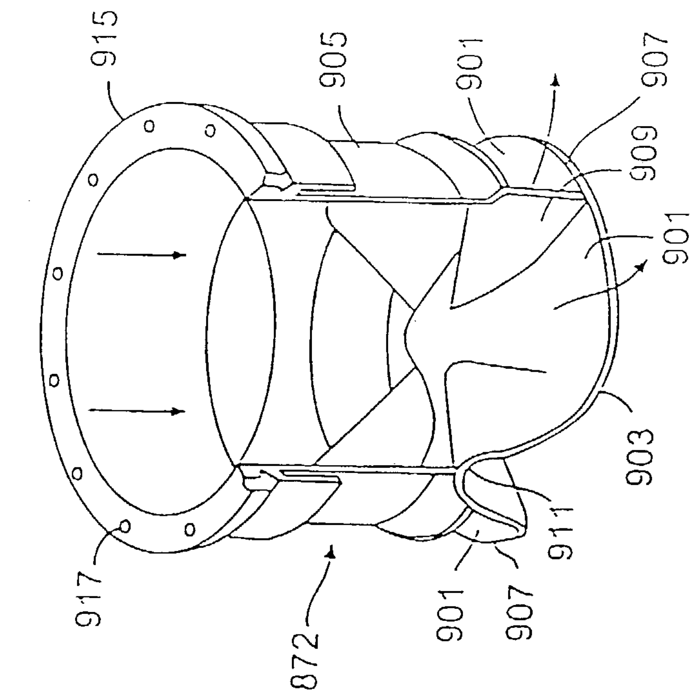
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FIG.11

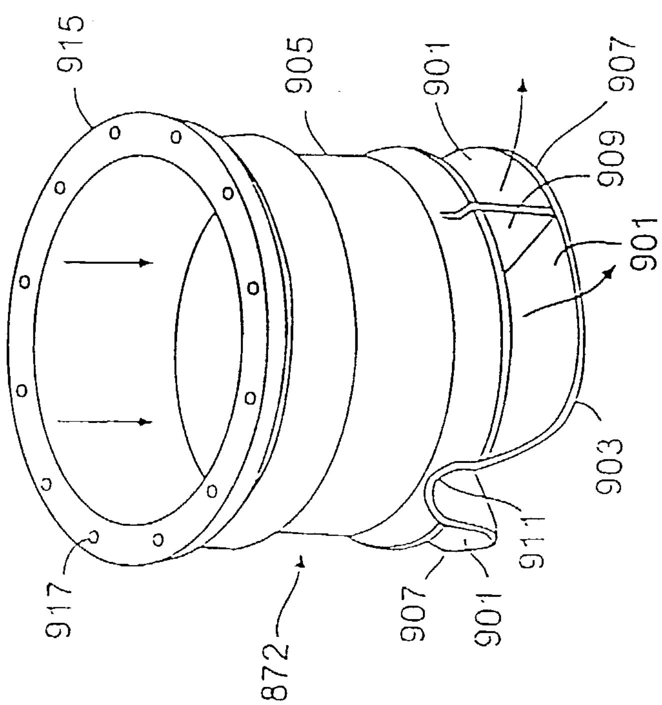
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FIG.10

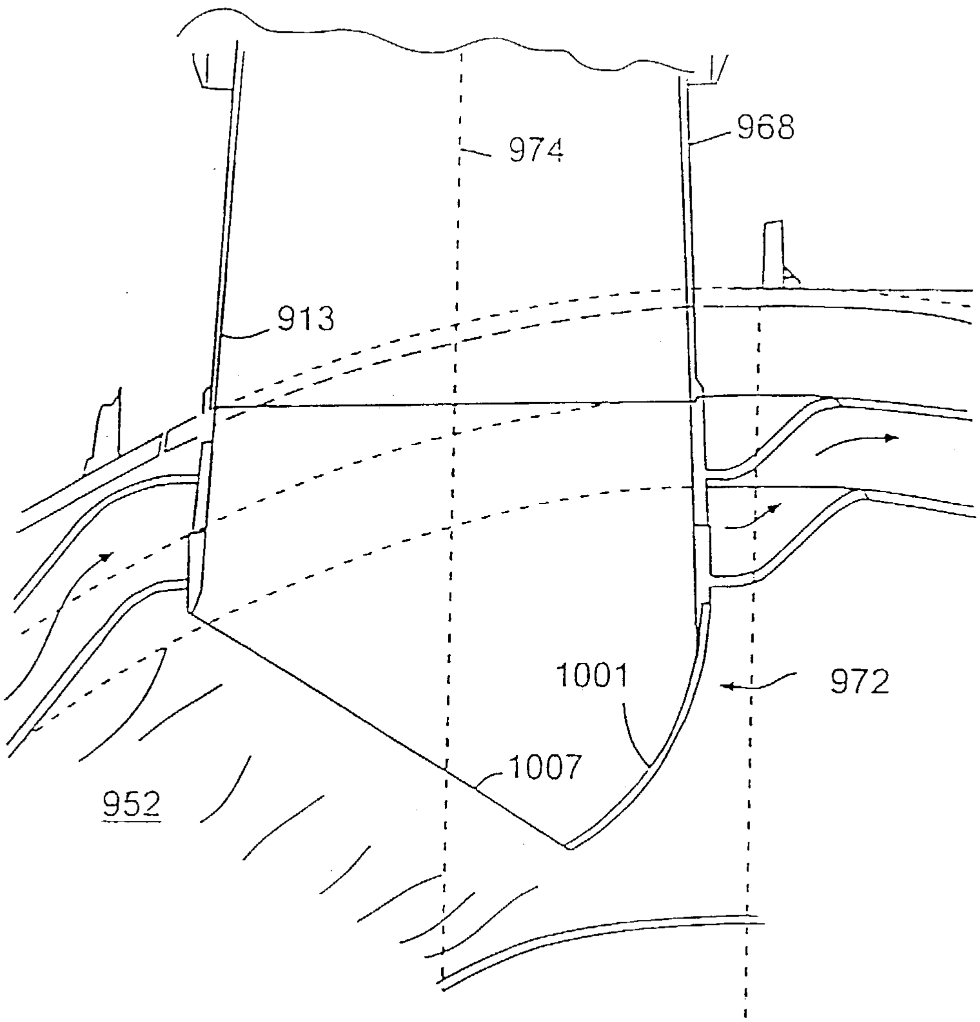
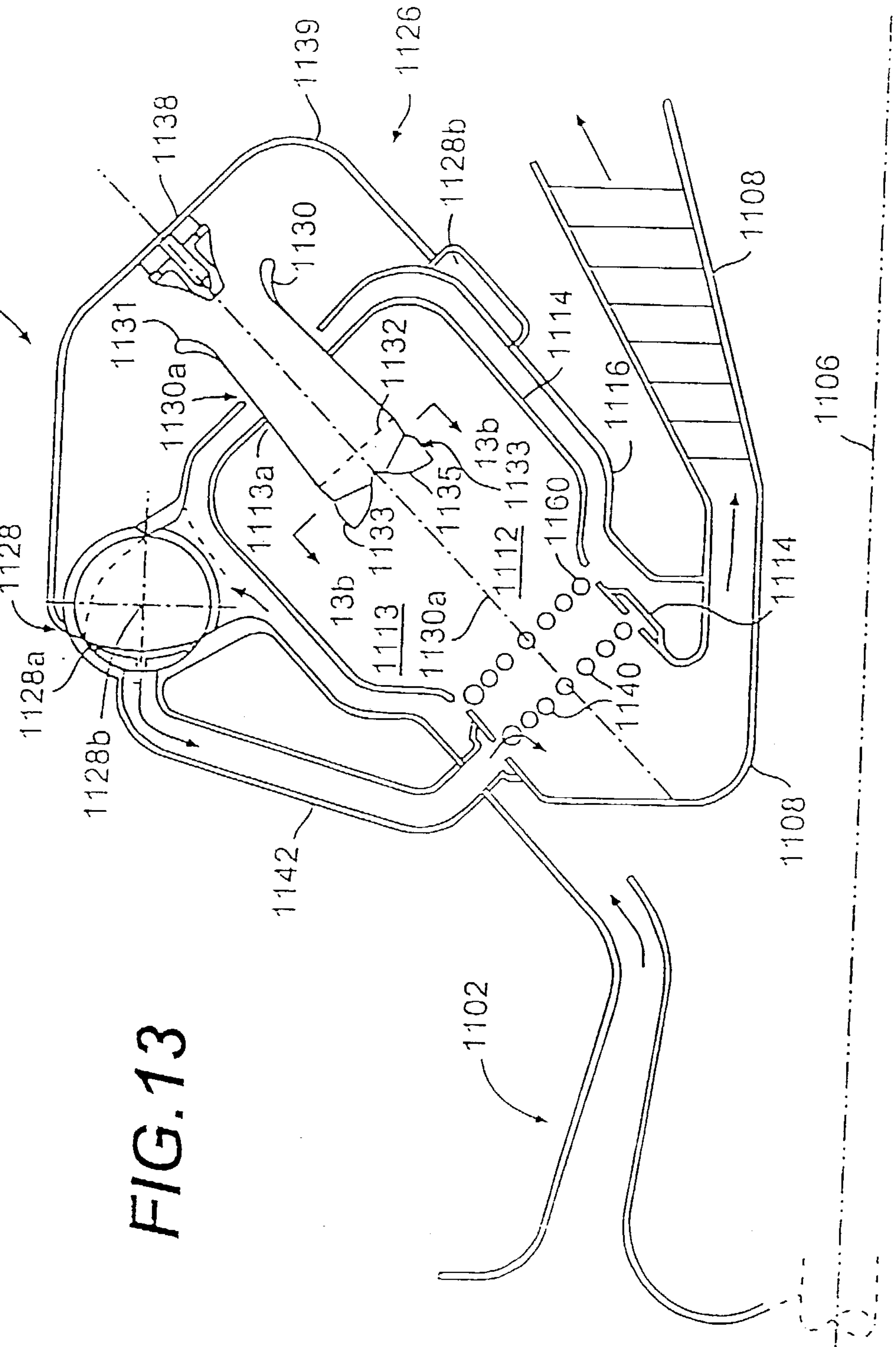


FIG.12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1128a
1128b
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1142
1102

FIG.13

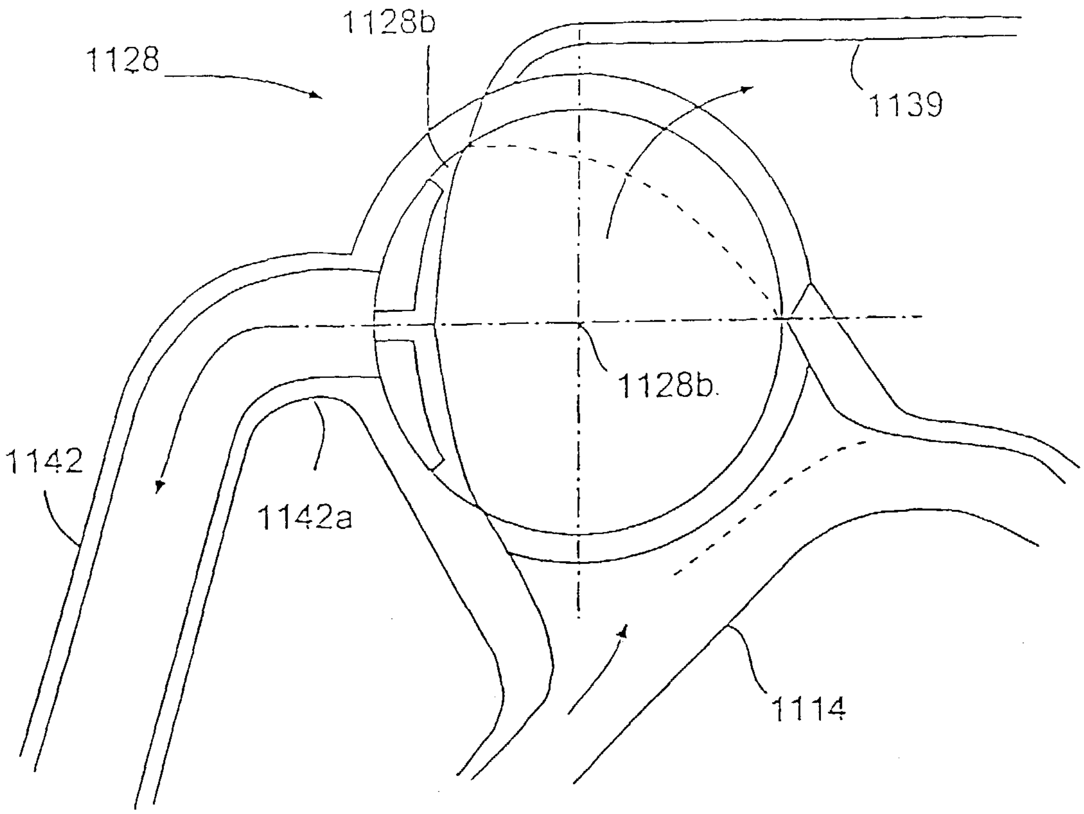


FIG.13A

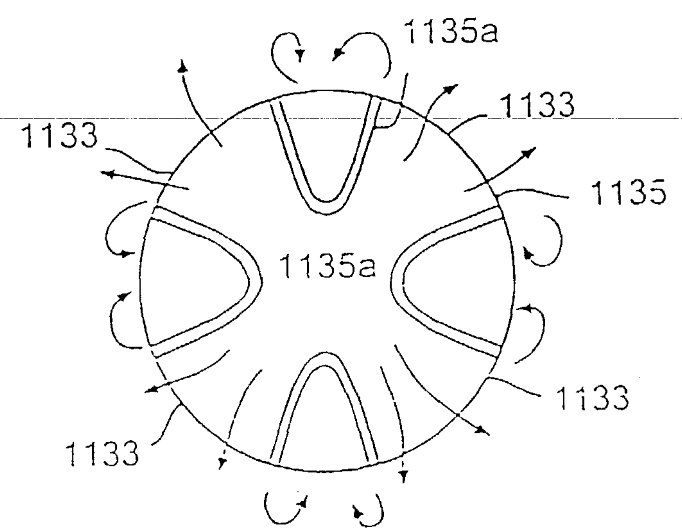
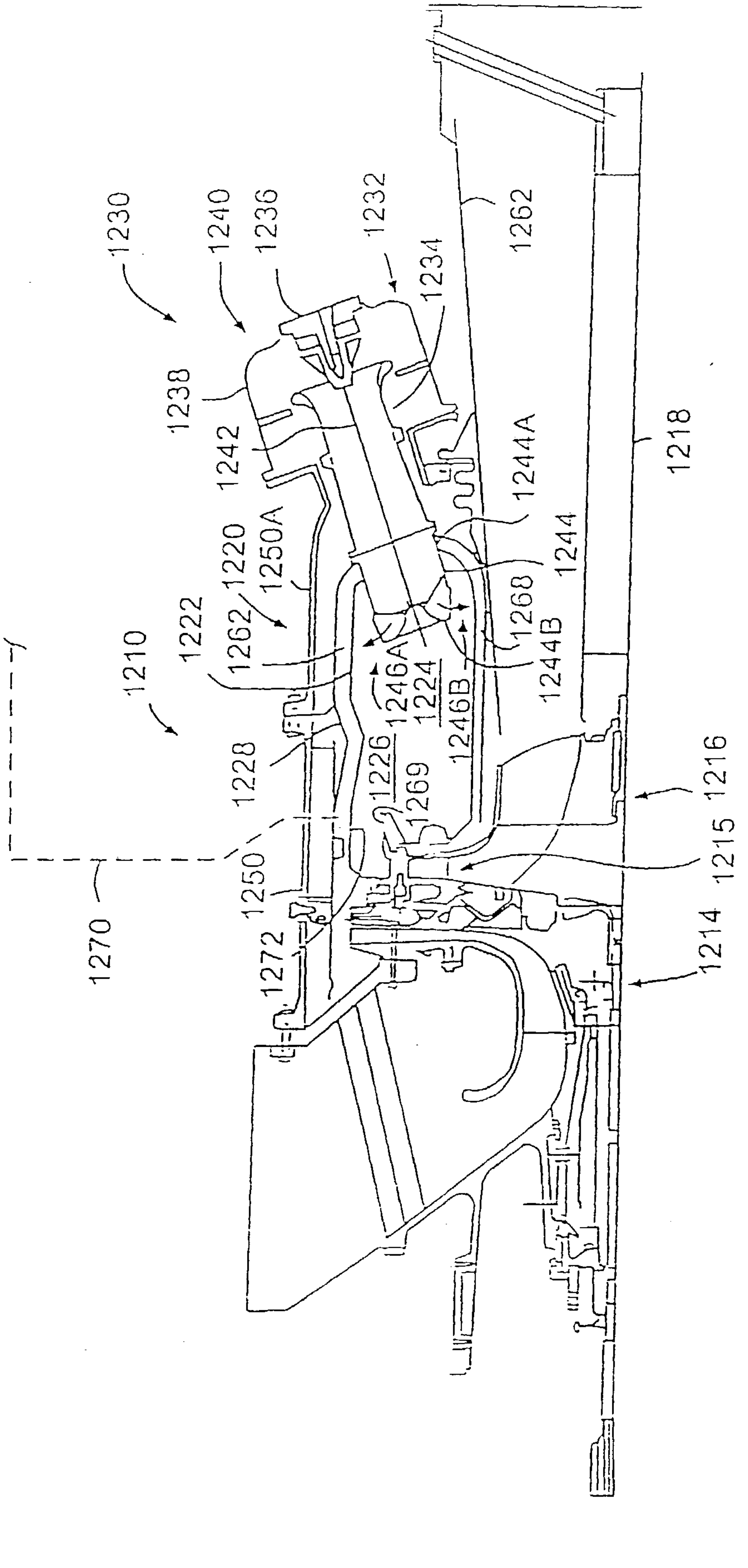


FIG.13B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1210
1246A
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1246B
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1216
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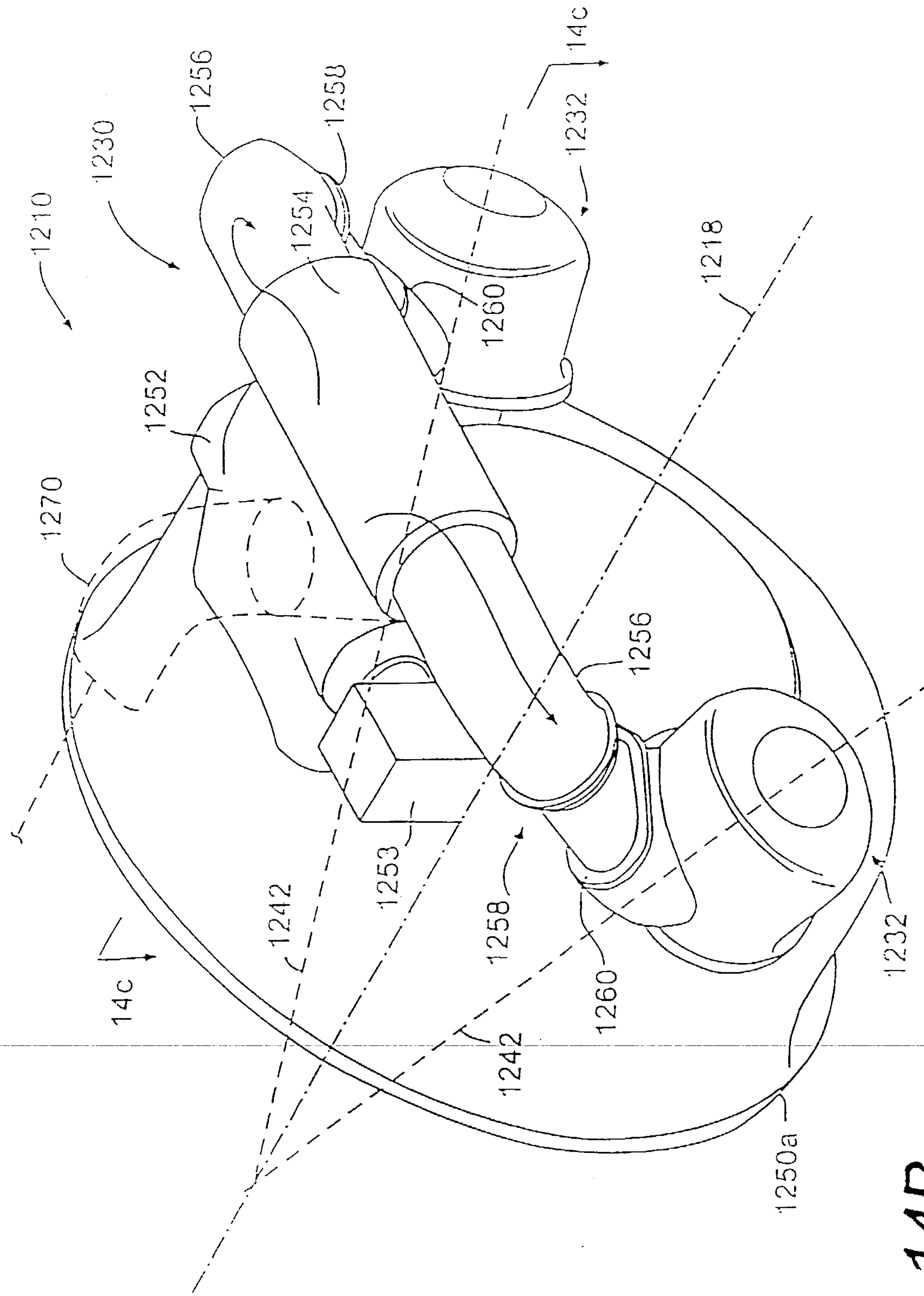
1272
1214

FIG. 14A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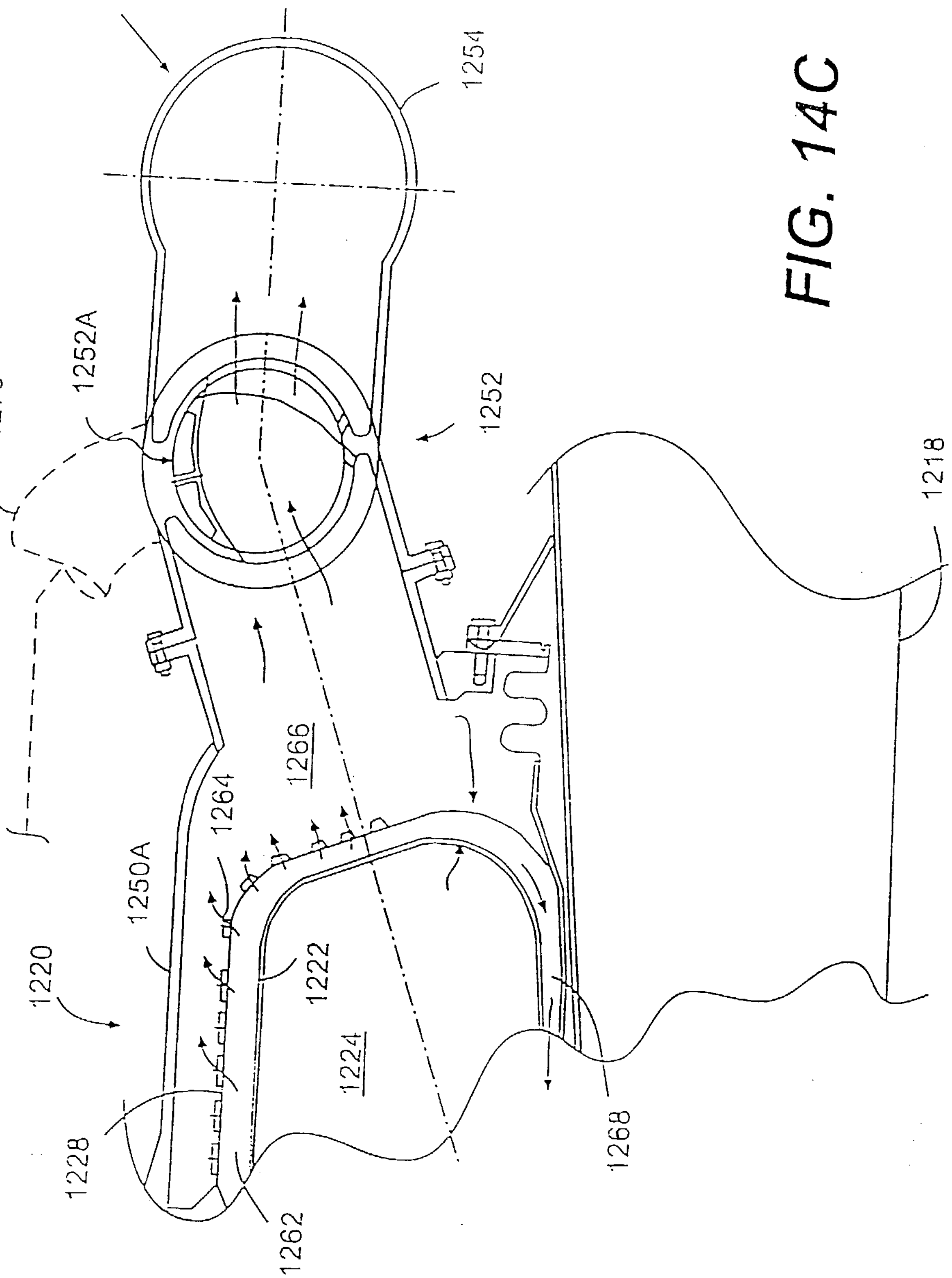
1232
14c
1242
1250a

FIG. 14B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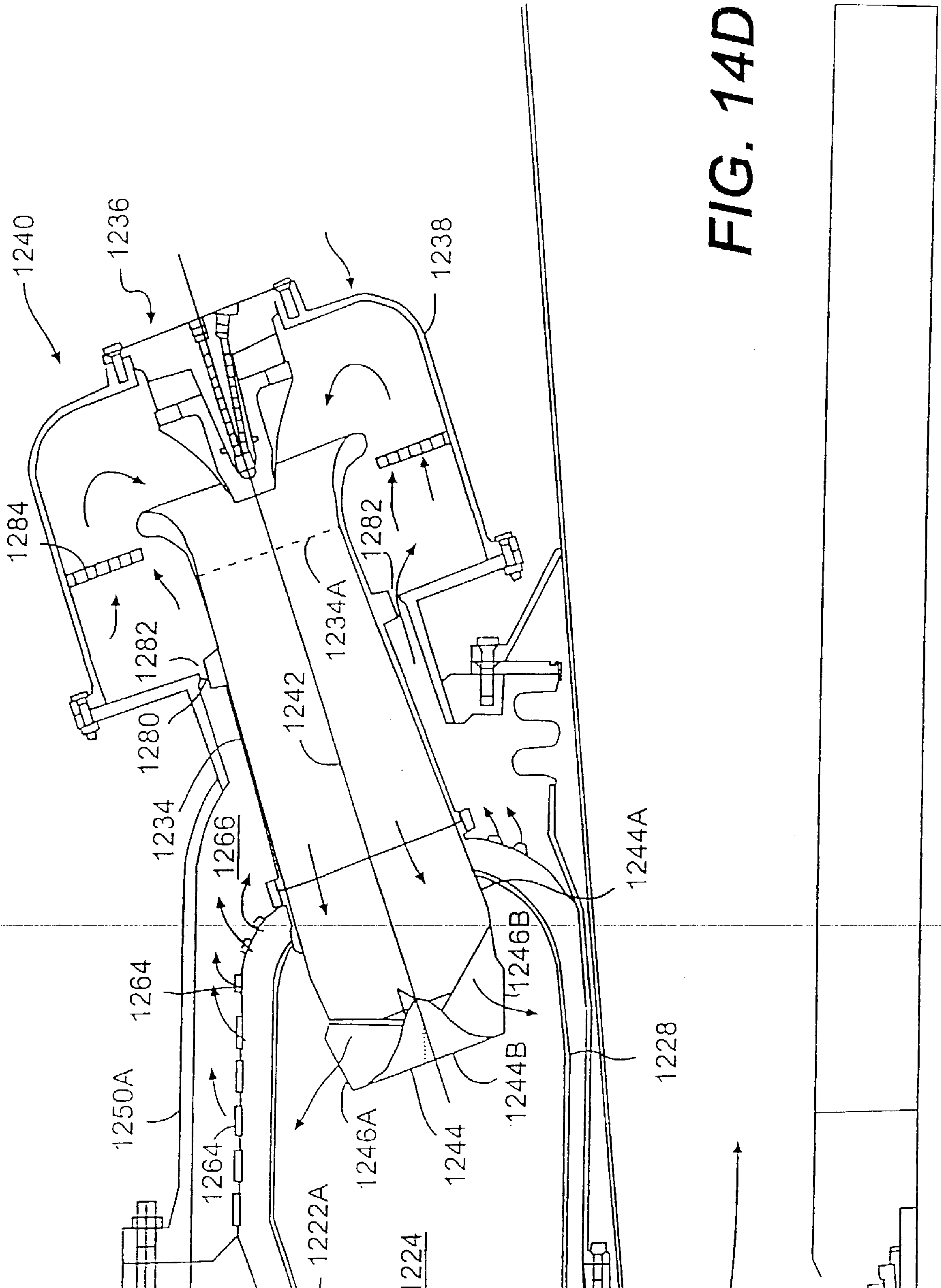
1262
1268

FIG. 14C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1244B
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1222A
1224
1262
1268

FIG. 14D

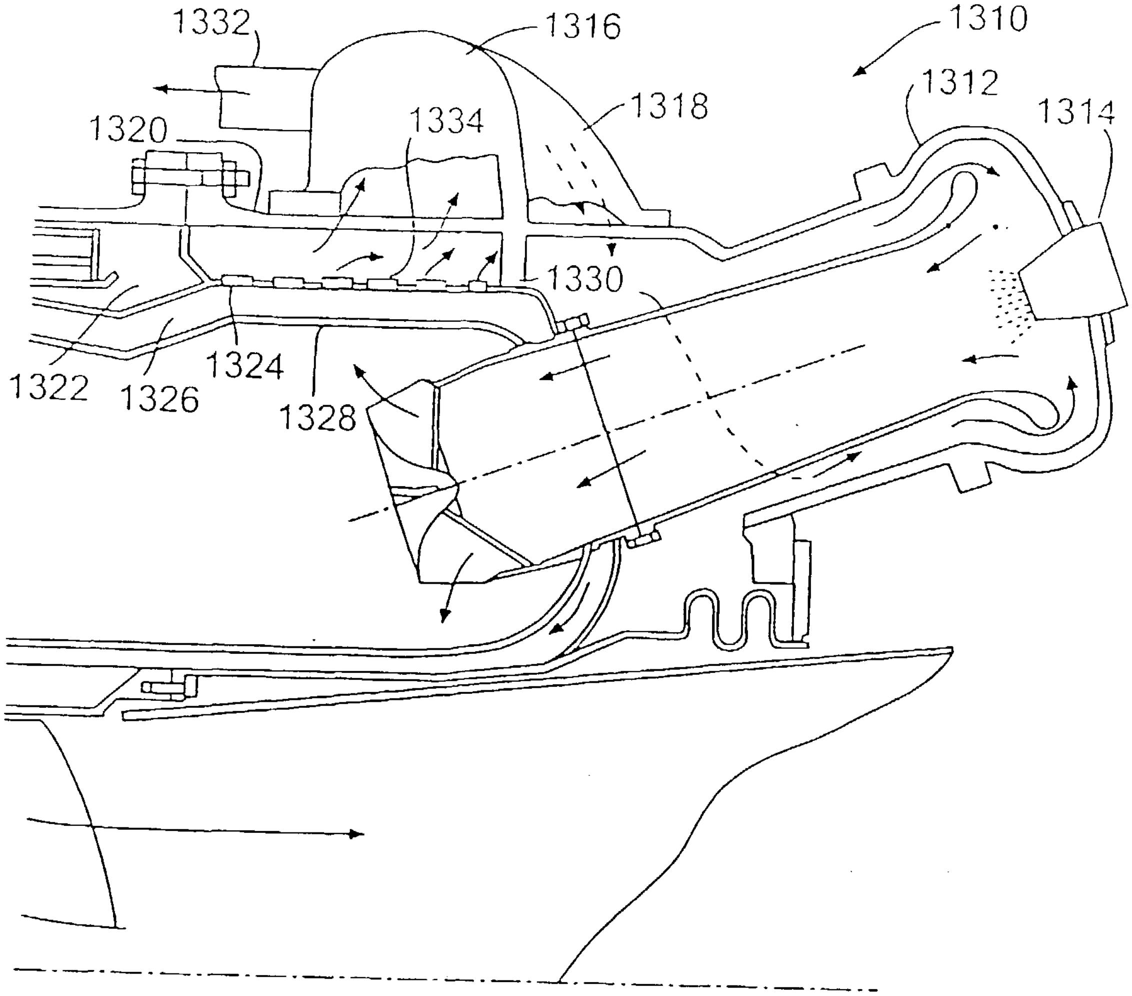


FIG. 15A

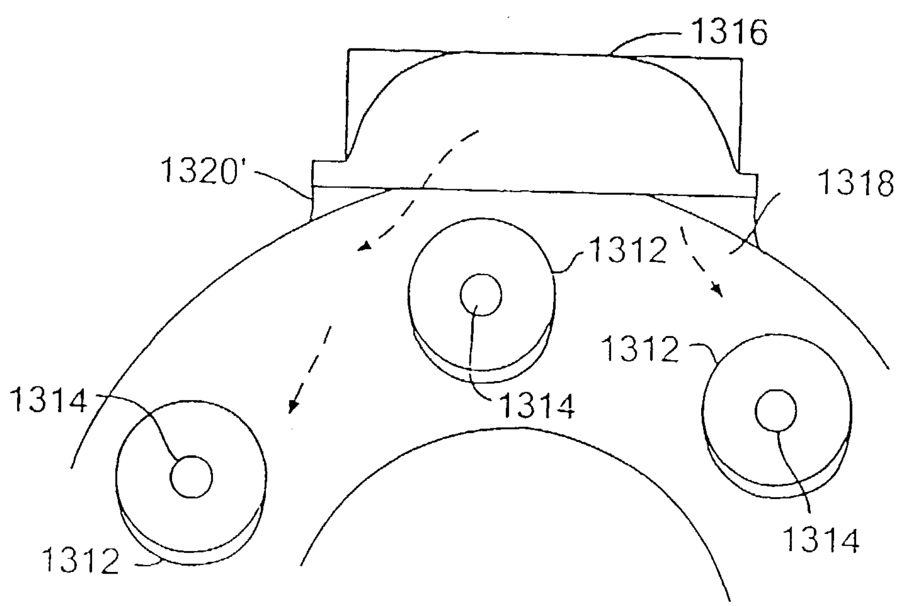
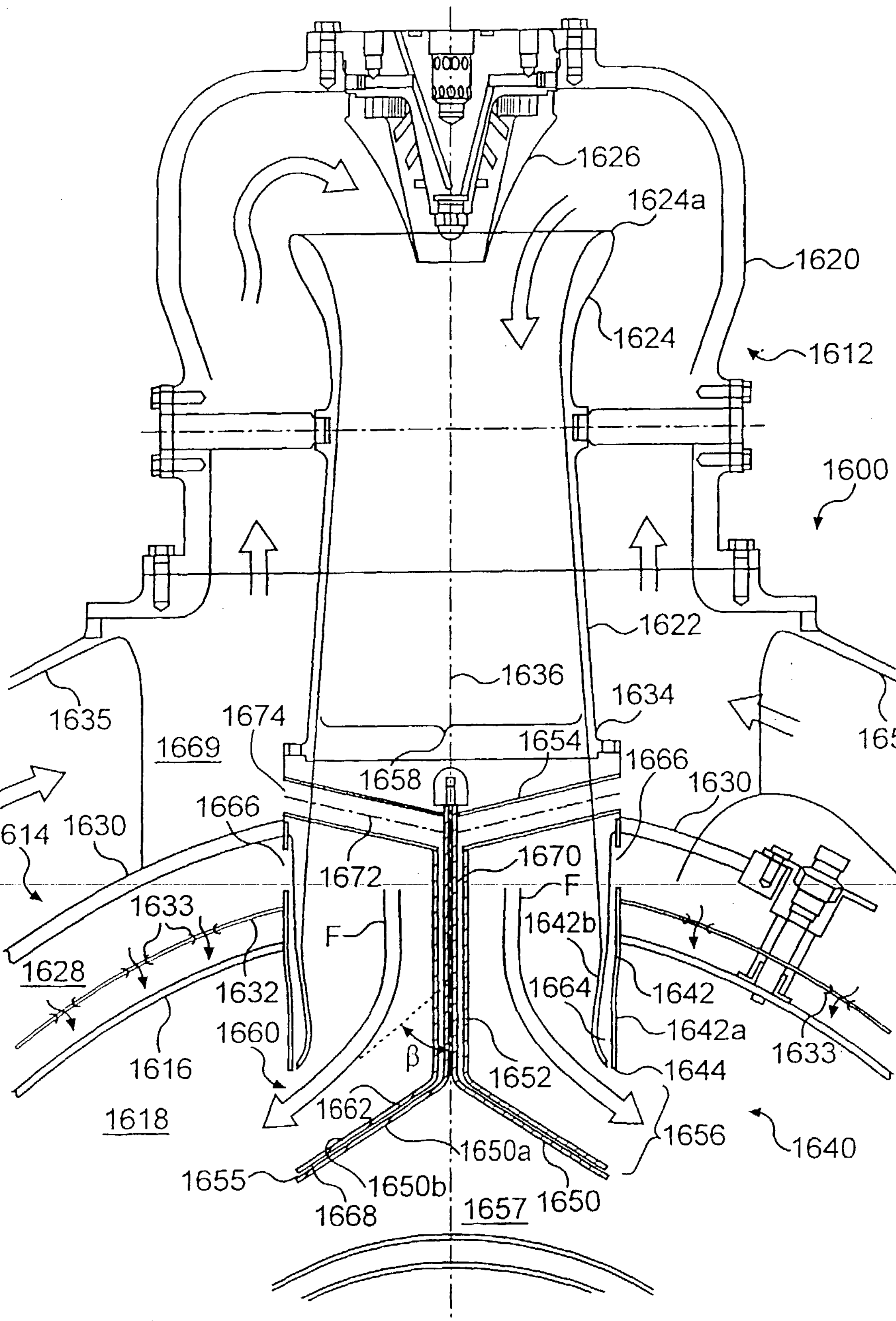


FIG. 15B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1672
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F
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1633
1642b
1628
1632
1664
1642
1642a
1660
1633
1616
β
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1644
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1655
1650b
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1657

FIG. 16

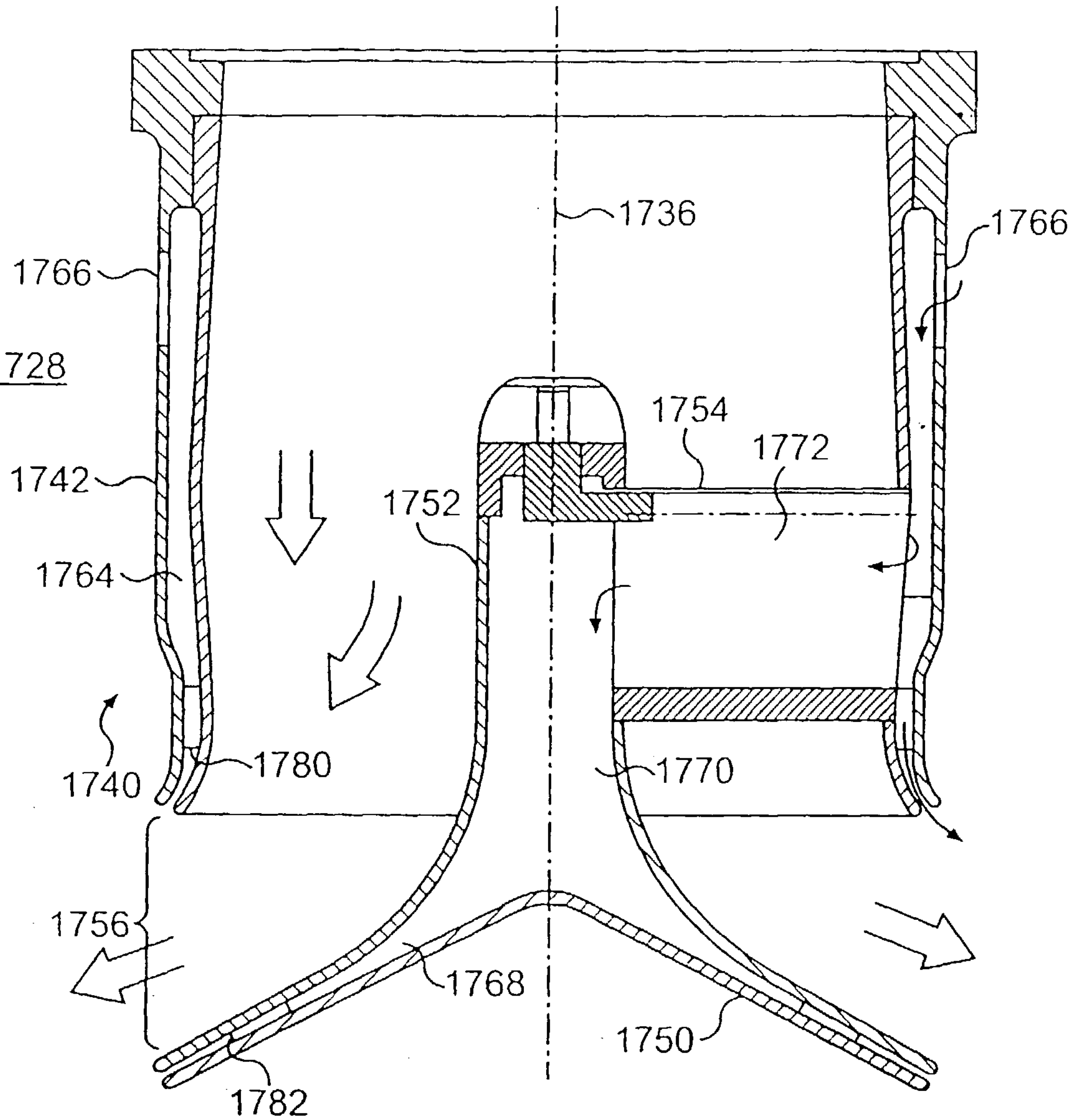


FIG. 17

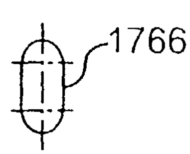


FIG. 17A

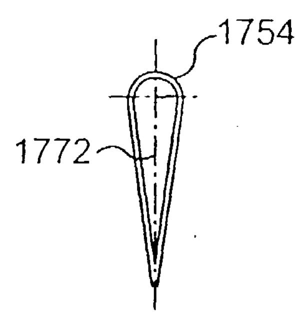
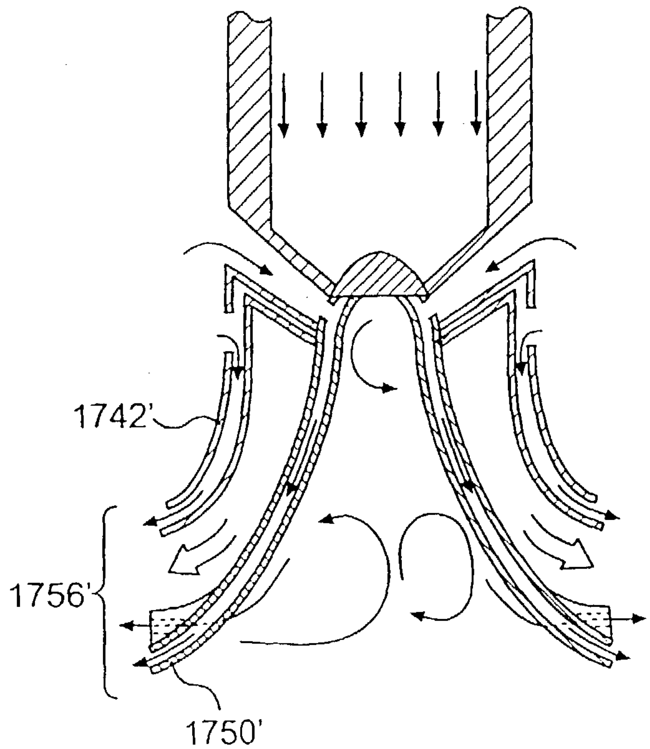


FIG. 17B

FIG. 17C



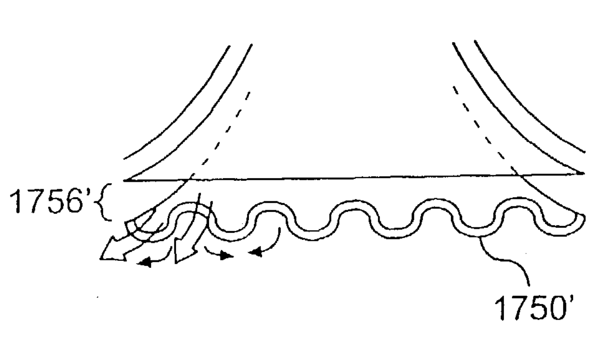


FIG. 17D

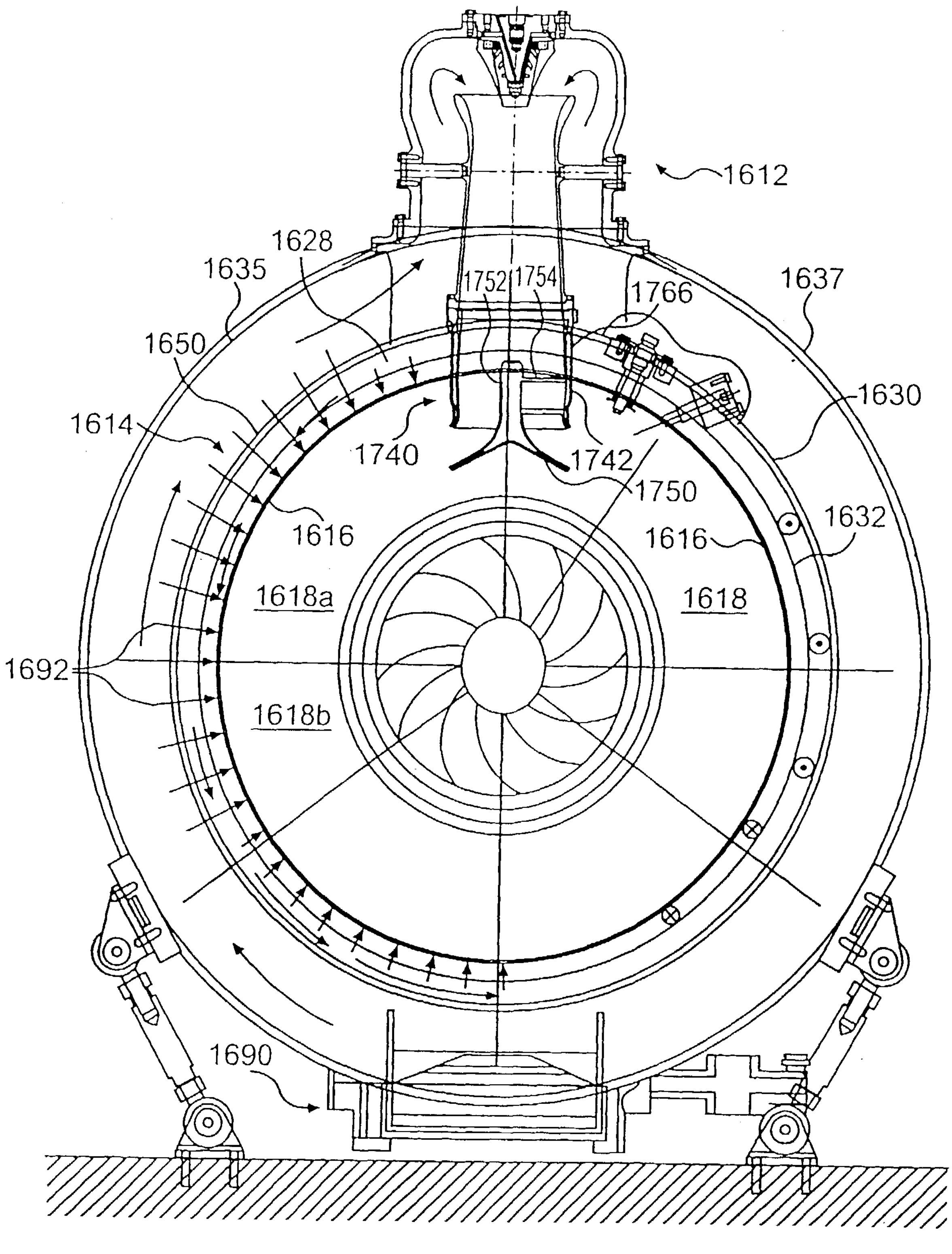

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FIG. 18

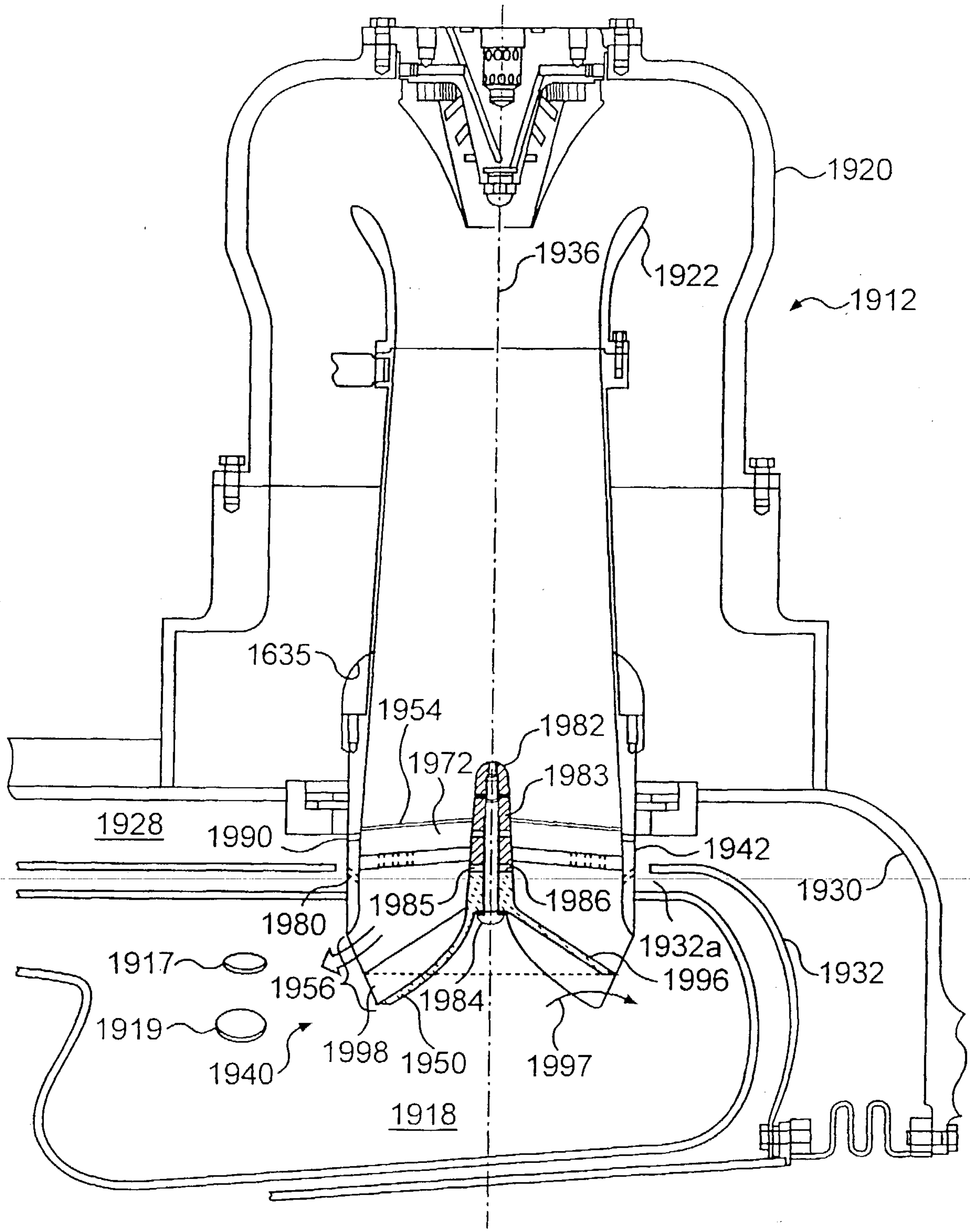
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FIG. 19

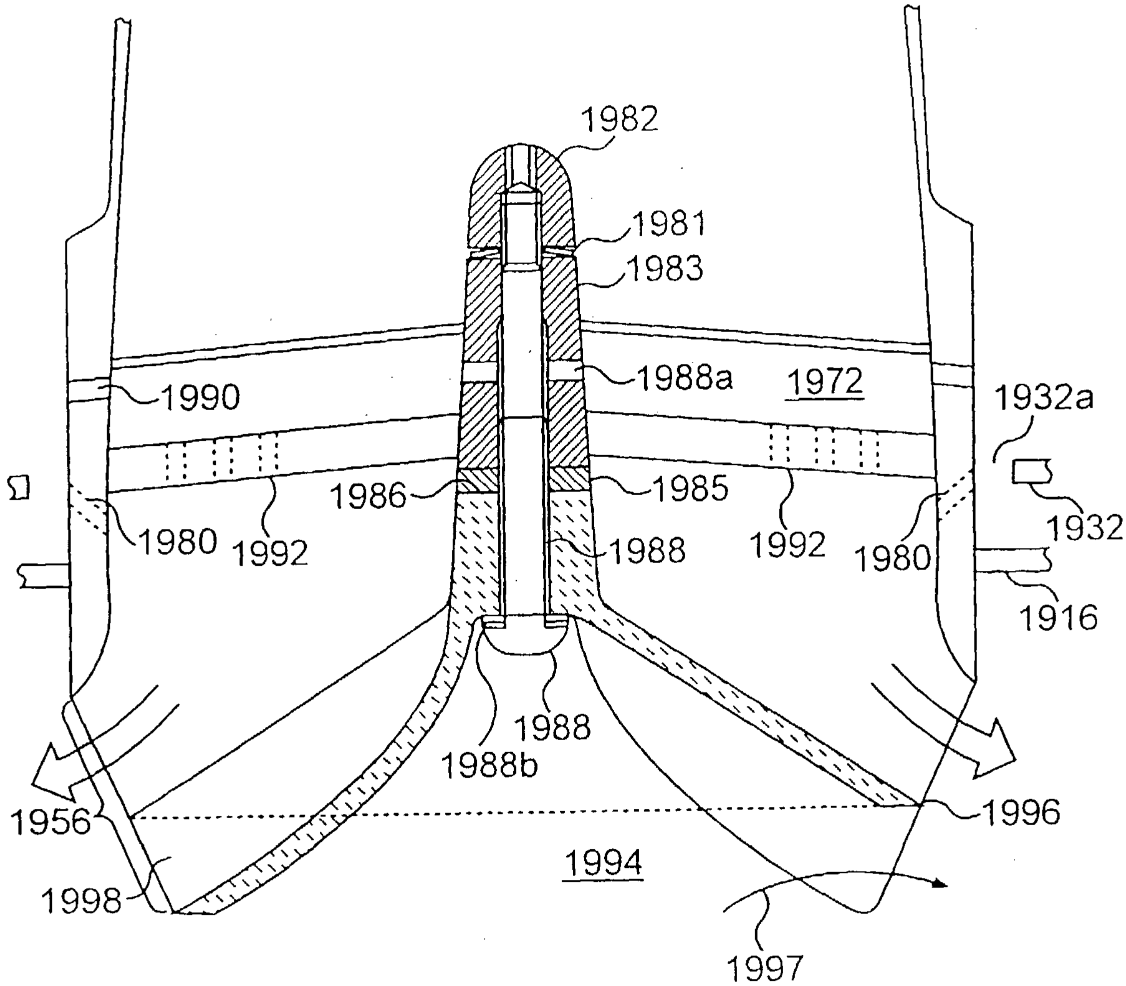

FIG. 19A

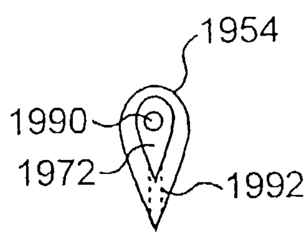

FIG. 19B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB 00/01899

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F23R3/28 F23R3/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F23R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 3 906 718 A (WOOD ROBERT DAVID) 23 September 1975 (1975-09-23) column 2, line 48 -column 5, line 52; figures 2,4,5	1-29
Y	EP 0 863 369 A (MOWILL ROLF JAN) 9 September 1998 (1998-09-09) cited in the application the whole document	1-29
Y	EP 0 445 652 A (MOWILL ROLF JAN) 11 September 1991 (1991-09-11) column 18, line 4 - line 32; figures 11,13 column 20, line 28 -column 21, line 21	1
A	US 3 851 466 A (VERDOUW A) 3 December 1974 (1974-12-03)	
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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Date of the actual completion of the international search	Date of mailing of the international search report
23 March 2001	03/04/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Iverus, D

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 611 879 A (ABB MANAGEMENT AG) 24 August 1994 (1994-08-24) ---	
A	EP 0 780 638 A (MOTOREN TURBINEN UNION) 25 June 1997 (1997-06-25) -----	

Int ional Application No
PCT/IB 00/01899

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 3906718	A	23-09-1975	GB	1427146	A	10-03-1976
			DE	2345282	A	21-03-1974
			FR	2199059	A	05-04-1974
			IT	998522	B	20-02-1976
			JP	1111618	C	31-08-1982
			JP	49124415	A	28-11-1974
			JP	56054537	B	26-12-1981
			US	3961475	A	08-06-1976
EP 0863369	A	09-09-1998	JP	11230548	A	27-08-1999
			US	5924276	A	20-07-1999
			JP	11201454	A	30-07-1999
EP 0445652	A	11-09-1991	US	5070700	A	10-12-1991
			US	5156002	A	20-10-1992
			CS	9100572	A	19-02-1992
			JP	6265146	A	20-09-1994
US 3851466	A	03-12-1974	CA	982831	A	03-02-1976
			DE	2415036	A	07-11-1974
			GB	1423799	A	04-02-1976
			JP	988872	C	29-02-1980
			JP	50002222	A	10-01-1975
			JP	54021482	B	31-07-1979
EP 0611879	A	24-08-1994	DE	4304989	A	25-08-1994
			JP	6248977	A	06-09-1994
EP 0780638	A	25-06-1997	DE	19547703	A	03-07-1997

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